The Role of Soils in the Terrestrial Carbon Balance (RSTCB)

An ESF scientific programme

Carbon stored in soils represents the largest terrestrial carbon pool. Consequently, we cannot begin to understand the controls on the terrestrial carbon balance until we have a thorough understanding of the "ins and outs" of soil carbon. In practice, however, most carbon balance research has focussed effort on the aboveground parts of ecosystems. It is not hard to see why. Whereas the carbon stocks and fluxes of the aboveground parts can be quantified with relative ease, those of the belowground parts cannot.

That is not to say, however, that little is known about the processes taking place within the soil. On the contrary, there exists a huge amount of knowledge relevant to the carbon cycle in soils. The main problem is that most of this knowledge resides with those engaged in "traditional" soil science, rather than with those engaged in carbon balance studies. This ESF programme has been set up to help break down the distinction between these two communities of scientists, and to develop closer integration with a third group of scientists, the modellers.

The programme seeks:

- *to increase confidence in soil carbon flux and stock change estimates to generate datasets that are reliable and consistent;*
- *to develop a new generation of models describing soil carbon dynamics;*
- *to investigate the effects of perturbation on soil carbon balance and the potential for mitigation of carbon emissions.*

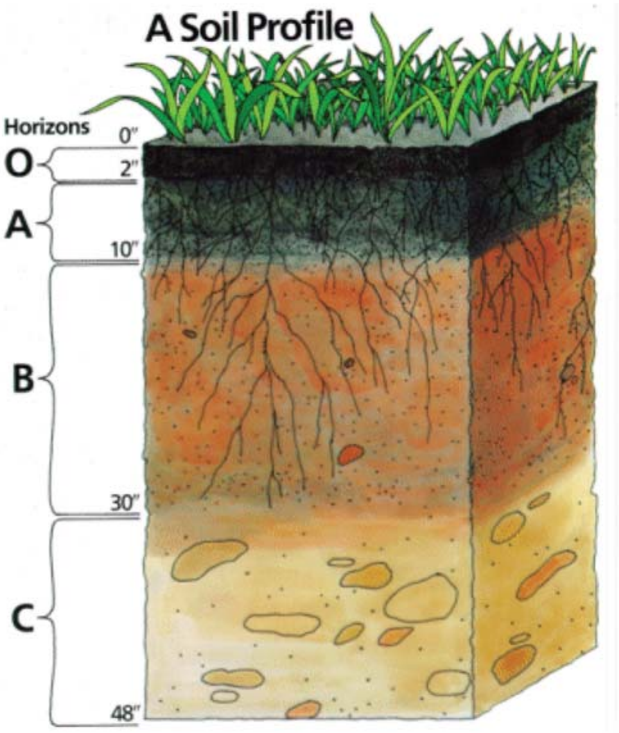
Activities include: workshops, summer schools, conferences and short-term fellowships.

The European Science Foundation acts as a catalyst for the development of science by bringing together leading scientists and funding agencies to debate, plan and implement pan-European initiatives.

Background

The largest terrestrial carbon pool

Carbon stored in soils represents the largest terrestrial carbon pool. Knowledge of the dynamics of this pool is essential if we are to understand the terrestrial carbon balance as a whole. Because inter-annual changes in soil carbon stocks are small compared to the total carbon stored in soils, determining the dynamics of the soil carbon pool by repeated "stocktaking" is difficult. Inaccuracies also confound attempts to measure, directly, the flux of CO_2 from the soil.



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Furthermore, we must also deal with considerable spatial and temporal variability – how do we "scale" measurements made at a limited number of locations, over a limited period, to provide a meaningful description of the long-term dynamics of soil carbon at the regional, continental and global scales?

Soils and climate change

Soils and climate change interface in two major ways.

Firstly, because the rate of carbon loss from soil is, to some extent, a function of temperature, soil carbon balance is likely to be a sensitive indicator of climate change. If soil carbon stocks become depleted, long-term sustainability of agricultural production on these soils becomes questionable.

Secondly, there has been considerable speculation, particularly in the US, about the potential for changing land management practices to increase the amount of carbon stored in soils as a means of offsetting CO_2 emissions from other sectors. The environmental and economic benefits of this form of carbon sequestration are huge, but as of now, we simply do not have the scientific basis with which to judge the theoretical and practical validity of these ideas.

Needs in soil carbon research

Thus there is a great and urgent need to develop methods of studying and describing soil carbon balance that are scientifically valid, and recognised as being so. At this time, however, we do not have a complete understanding of the various soil processes that affect carbon. Equally importantly, none of the models that we currently use summarise all the understanding we do have.

Achieving an international consensus on how to include soils in carbon accounting procedures demands that methods of determining, reporting and verifying changes in soil carbon stocks are scientifically valid. To contribute to this, soil carbon research must become more coherent, and must develop greater linkages between pure- and applied scientists, between modellers and experimentalists and between scientists, economists and policy-makers.

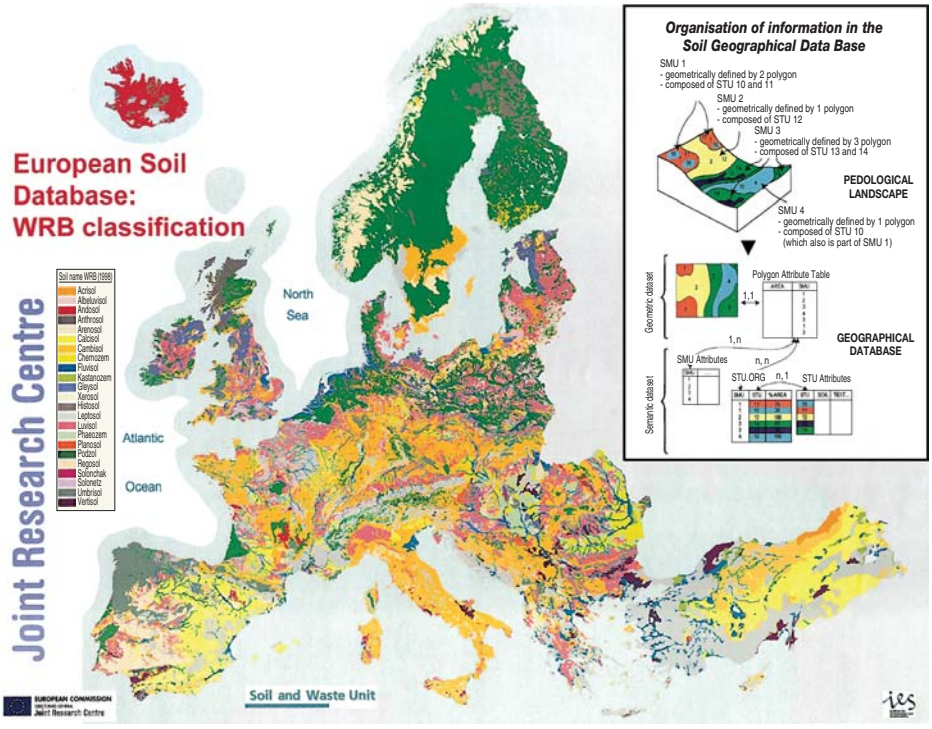
The ESF programme

A multidisciplinary programme

In general, the question of understanding soil carbon balance is of major concern to two, quite distinct, scientific communities: soil scientists and carbon budget researchers what we can loosely call the flux measuring community. Soil scientists have traditionally been concerned with describing general trends in soil carbon stocks, carbon budget communities are interested in soil carbon dynamics because they want to understand carbon fluxes of ecosystems. It is recognised by the ESF that scientific progress is made when bridges are built between disparate scientific disciplines, and it is the overarching aim of this programme to foster synergistic interaction between these two groups. We further hope to develop collaborations with yet more scientific communities, for example microbiologists, plant physiologists, chemists and atmospheric physicists.

Modelling is an example of a topic where the interdisciplinary approach taken by the proposed programme could lead to considerable progress. Models produced by soil scientists tend to have long time-steps, and tend to focus on partitioning the soil carbon pool into different sub-pools. These models are generally very good at reproducing, for example, geo-climatic influences on soil carbon distribution, but are less good at describing fine resolution details such as the carbon fluxes at individual sites. On the other hand, the models used by the flux measuring community tend to be short time-step models describing instantaneous soil CO_2 efflux. These models explain most of the daily and annual variation of the CO_2 efflux at particular sites but cannot explain differences between sites and do not attempt to describe long-term carbon dynamics. We hope to bring together these different modelling communities, to bridge the gap in our modelling efforts, and to facilitate the development of a new generation of soil carbon balance models – ones that can describe fluxes well at the individual site level as well as longer-term trends in soil organic carbon across many sites.

The programme will bring together scientists to find ways of reducing uncertainties associated with stock change and flux estimates at site, national and



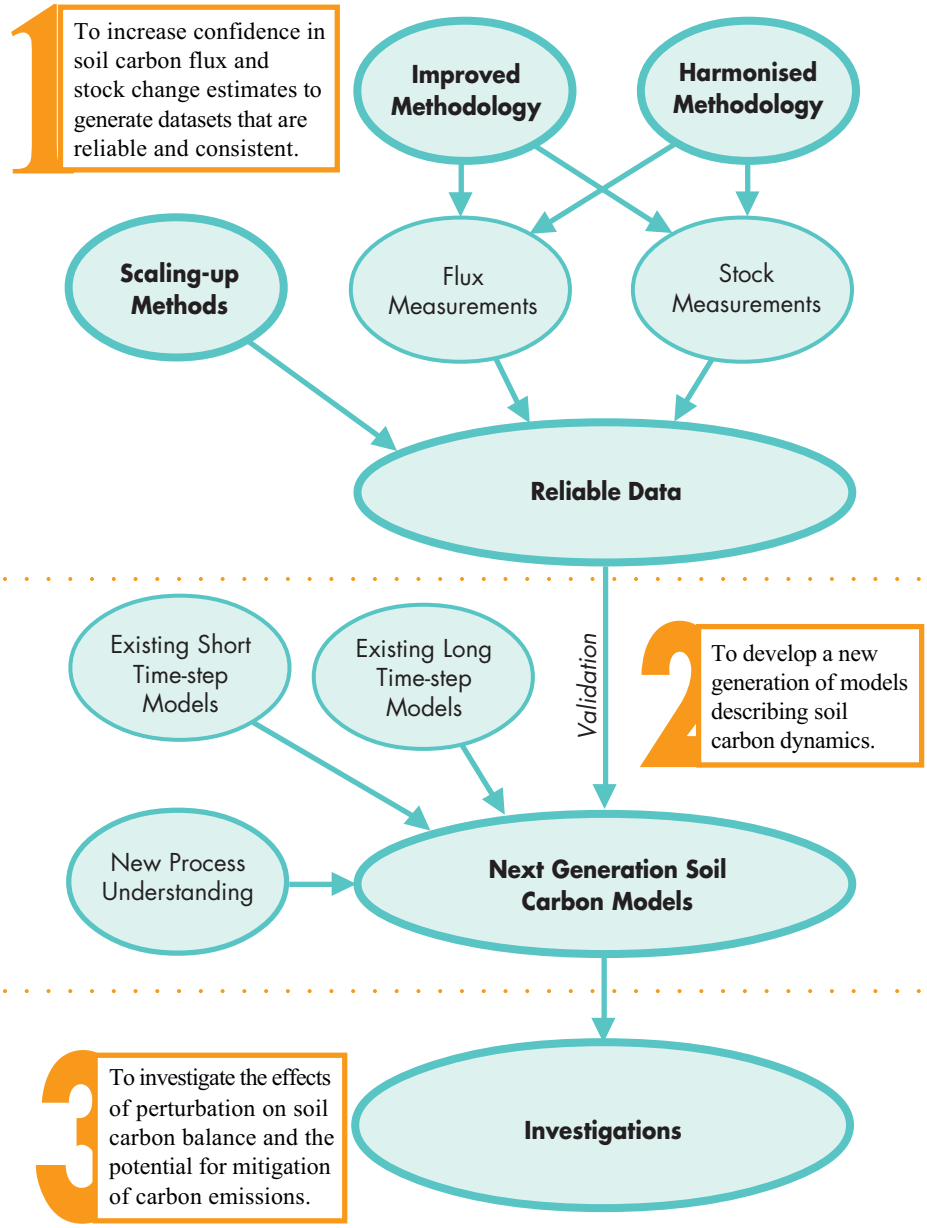
Soil map of Europe

continental levels. This will be done by devising means of cross-validating carbon stock changes inferred from flux measurements and directly measured stock changes.

A European level programme

Soils in Europe span the range from the massive carbon stores in the boreal region to the semi-arid, desertification-prone soils of the Mediterranean, and from the rich, intensively farmed soils of the low counties to the thin, erosion-prone Alpine soils. At the national level, individual countries tend to fund research focussing on their own, local, conditions and concerns. There is a powerful case for having a consolidated research effort into the terrestrial carbon balance at the continental scale. The beginning of the first Kyoto commitment period in 2008 underlines the urgent need for action. This programme aims to bring together soil carbon researchers from all these regions to create a whole-Europe perspective on the role of soils in the terrestrial carbon balance.

Scope and scientific objectives



The structure of the programme. Items in bold are activities and products.

Increasing confidence in carbon flux and carbon stock estimates

The first step towards understanding the soil carbon balance is to be able to make accurate measurements of soil carbon dynamics, notably CO_2 fluxes and carbon stock changes. The difficulties of measuring soil CO_2 fluxes are well documented, but measuring the carbon stock of soils is no less difficult. Two major uncertainties remain. First is the difficulty in getting a spatially representative measurement. Geostatistics can help us predict how many samples are needed to bring our estimates to within an acceptable error range. But will it ever be economically feasible to measure small enough changes in carbon stocks against the large carbon stocks present in most soils? Second, should we concern ourselves with total organic carbon or should we equate "sequestered" carbon with carbon that is completely inert (recalcitrant)? Clarifying these issues will be the focus of workshops within the programme.

Dealing with heterogeneity and scale provides methodological challenges in the design of experiments to investigate soil carbon balance. Two are particularly important at the European level. Firstly, there is a need to describe the soil carbon balance of ALL Europe. The proposed programme will include people from every part of Europe and will stimulate the European perspective necessary for successful integration of local measurements to the regional and continental scales. Secondly, we need to devise ways to investigate the long-term behaviour of the soil carbon balance. The difficulties of studying long-term phenomena within a reasonable time-period are obvious, and require that novel experimental methods and modelling techniques be developed. What sorts of methods can we use when our objectives are so large-scale and long-term? What combination of local measurements, remote sensing and modelling yields the most useful/reliable estimates? This programme will provide the opportunity for assessing scientific priorities and formulating the ideas necessary to address them.

A new generation of soil carbon dynamics models

Several disparities suggest that we need a new generation of models to describe soil carbon dynamics. Firstly, the disparity between what we have now and what we need, and secondly, the disparity between what we know and what is currently included in our models. Whilst there is unlikely to be a single ubiquitous model, we hope that by bringing together scientists from different disciplines, (pure scientists with new process understanding, modellers with experience of describing processes mathematically, ecologists with access to various datasets, etc.) we can create a state-of-the-art modelling framework that can be simplified in different ways according to different users requirements.

The effects of perturbation and the potential for mitigation

To compliment and build on the scientific and modelling advances that will come out of the programme, we will consider two questions: What are the effects of environmental perturbation on soil carbon balance and what is the potential for using soils to mitigate CO_2 emissions.

Perturbations may be caused by climate change, they may be a normal part of the land-use routine (e.g. disturbances in agriculture or forestry rotations), or they may be the consequence of a policy-driven change in management practice. The effects of these perturbations are huge. For example, an estimated 100 billion tonnes of soil carbon has been lost through human activity, particularly agriculture. In the latter part of the

programme, we hope to use the model structure we have built up to explore the possible consequences of present and future perturbations.

Although organic matter in soils is already the largest terrestrial carbon pool, there is speculation that potential exists to increase the amount of carbon stored in soils still further. Over the next 50 to 100 years, it is estimated that between 40 and 80 billion tonnes of carbon could be sequestered in agricultural soils alone. On the other hand, there is a body of opinion that soil carbon stocks are governed by geo-climatic factors, and the potential for mitigating CO_2 emissions by carbon sequestration in soils is overestimated. As carbon "credits" become a recognised commodity, there is a need for science to address the assumptions upon which these differing opinions are based. This programme will provide the forum and modelling tools that will allow us to consider the carbon sequestration question in its entirety – from the basic science governing the dynamics of soil carbon stocks, to the cost-benefit analyses of, for example, taking land out of agricultural production and managing it for carbon sequestration.

For these tasks, the programme will include scientists from out with the soil community, for example agricultural economists and land use planners. In this way, we will generate two-way dialogues that inform the wider global change debate with soil-related scientific knowledge as well as adding relevance to our own scientific work by placing it in a broader context.

Activities

Workshops

The programme will fund a series of workshops relevant to the scientific objectives. Each will draw together between 20 and 40 scientists from across Europe and across scientific disciplines. Although the scientific priorities will develop and evolve over the course of the programme, we expect to hold the following workshops in the initial part of the programme.

- *Methods of quantifying soil carbon stock changes*

The workshop will develop and share best practices for quantification of soil carbon stock changes. We will consider not only the mechanics of sampling soil for carbon content, but also the statistics governing an effective sampling strategy and which set of chemical analyses we consider essential for correctly describing the various soil carbon pools.

- *Towards the next generation of soil carbon models*

The workshop will pose questions such as,
"In what ways can we make our existing models more useful?"
"How can we marry short and long time-step models?"
"Which processes must be described to bring models to the state of the art?"
"Can we find ways to validate the long-term behaviour of models with existing carbon flux and carbon stock data?"

Short-term fellowships

Each year, a call will be made for scientists to apply for short-term fellowships that will enable them to spend time working in other research groups. Only applications that propose an exchange between two different countries will be considered, and preference will be given to young researchers from countries contributing to the programme.

Conferences

Two conferences will be funded, a small conference towards the start of the programme, and a major international conference in the final year.

Summer school

The technical skills associated with soil carbon research can be demanding, and expertise in these fields is thinly spread between researchers in many locations. Because of this, we intend to run a weeklong summer school where around 20 postgraduate students and young researchers will be introduced to the fundamental skills required for a research career in this area. The topics covered will be quantification of carbon stocks, flux measurements, physical and chemical analysis, basic microbiological methods and process modelling, and each topic will be taught by a recognised expert in that field.

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For the latest information on this programme consult the *RSTCB* home page: www.esf.org/rstcb

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