EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

Exploratory Workshop Scheme

Standing Committee for Life, Earth and Environmental Sciences (LESC)

ESF Exploratory Workshop on

Diurnal- to century-scale controls on soil respiratory fluxes.

Towards a new generation of integrated experimental and modelling approaches

Innsbruck (Austria), 20 – 23 September 2009

SCIENTIFIC REPORT

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1. Executive Summary

The main objective of the workshop was to explore possibilities of collaborative efforts developing and applying novel experimental and modelling approaches for obtaining an integrated perspective on diurnal- to century-controls on soil respiratory fluxes. The particular aims and tasks of the workshop were to 1) identify factors determining patterns of soil respiration emerging at different spatial and temporal scales (with a particular reference to automated measurements of soil respiration and soil CO_2 profiles, as well as experiments manipulating single or combined environmental factors); 2) synthesize and improve current approaches to disentangling abiotic and biotic effects on soil respiration and its components (with an emphasis on isotopic approaches); 3) define strategies for model-data integration and develop a conceptual framework for modelling approaches integrating flux-based and SOM-based models; 4) identify the requirements emerging from 1-3 for future networking/ collaborative research activities integrating experiments and modelling in a concerted effort.

The first part of the workshop elaborated the state of the art, as based on a combination of short lectures, poster presentations and both plenary and breakout group discussions. It was found that 1) the previously hypothesized close link between canopy photosynthesis and soil respiration is likely to exist, but the interpretation of its mechanisms is obscured by the involvement of a range of different C pools; 2) biotic interactions are important, including the differential use of fresh C by different soil components (root – mycorrhizal) and groups (microbial, faunal), as well as priming effects; 3) soil organic carbon turnover models should separate the physico-chemical from enzymatic processes and be more strongly based on model-data integration approaches.

In the second part of the workshop, overarching and specific research questions were discussed and potential approaches were outlined. The main research topics that need to be addressed in the future include:

• the plant-soil C transfer, as related to plant C allocation and below-ground C partitioning, in relation to the nitrogen cycle, soil and vegetation type, and phenology, and as affected by changing environmental conditions;

• soil C turnover, in particular effects the quality and quantity of soil C input (litter, exudates, DOC, DIC) on decomposition and mechanisms of stabilization and

destabilization (aggregates, priming), including aspects of soil type, vegetation type, and the N cycle;

• the role of biota for SOM pools and fluxes, including effects of different functional groups (e.g. fungi/bacteria, soil fauna);

• soil C models, particularly as concerns their suitability for climate change scenarios, separating physico-chemical from enzymatic processes; improved representation of SOM pools and isotopes, improved description of physico-chemical stabilization and the interface between ecophysiology (C allocation) and soil modules; representation of vertical heterogeneity and biotic interactions.

Experimental approaches to achieve progress in these fields include both mescocosm and field studies across environmental transects, using a combination of isotopic labelling approaches (including continuous and pulse labelling); the manipulation of below-ground C allocation, the monitoring of microbial population dynamics of soil biota, and the study of the role of biota for the stabilization and de-stabilization of SOM, as related to soil physics and changes in physical and chemical environment by biota. Model-data integration and a improved representation of the above parameters in models will likely stimulate progress both for developing experimental designs and for the improvement of models describing and predicting soil C fluxes across timescales from diel to centuries.

At the of the workshop a number of possible follow-up activities were discussed and envisaged, including a number of synthesis publications, an ESF research network, a Marie Curie Training Network and a EUROCORES proposal.

2. Scientific content of the event and

3. Assessment of the results, contribution to the future direction of the field

The scientific content and the results of this exploratory workshop include:

1) an overview and a synthesis of recent developments in the field,
2) an identification of gaps in our knowledge and related general and specific research questions,
3) the development of a set of approaches that should help addressing these research questions most consistently, and
4) the identification of possible follow-up activities, including networking, synthesis publications and the development of collaborative research activities.

State of the art

The first part of the workshop was devoted to obtaining an overview of recent developments in the field. This was achieved with a combination of short lectures and poster presentations and was deepened in subsequent plenary and breakout group discussions. Recent insights include the following:

- Patterns emerging from datasets obtained with automated soil respiration (SR) systems confirm a previously hypothesized short-term coupling between canopy photosynthesis (GPP) and SR only partly. It appears that there might be a fast link between these processes at the timescale of hours and a slower one at the timescale of a few days. Possible mechanisms might include phloem transport, pressure-driven exudation and plant internal circadian patterns, but these still need to be explored in some detail in experimental studies.
- Isotopic studies suggest that the transfer of carbon (C) from the canopy to the soil occurs within hours (herbaceous species) to days (trees). The interpretation of isotopic signatures is complicated by apparent isotopic fractionation, which may result from a combination of respiratory fractionation (differing for different pathways) and a re-fixation of root respired CO_2 and its upward export by plants, causing a mixing of different substrate pools.

- Fresh photoassimilates entering the soil are mainly transferred to fungal and less to bacterial components. Strong differences in the uptake of fresh plant-derived C by different faunal groups have been observed. Mycorrhizal respiration has been found to be more strongly coupled to fresh (excess?) C than root respiration.
- Effects of fresh organic carbon on soil organic matter (SOM) turnover ('priming effects') are increasingly considered as a key process and thus need to be represented in models. Such priming effects should be linked to microbial biomass, as well as different microbial groups.
- Soil carbon turnover models have been successful in describing effects of land use, but may be less suitable for assessing impacts of climate change. This limitation could be overcome by separating physico-chemical (aggregation, sorption-desorption, hydrophobicity) from enzymatic processes. Furthermore, SOM pools should not be based on age, but on process. Such a new generation of models would ideally be structured in a modular way, including modules on microbiology, plant C inputs, SOM quality (distinguishing assimilable versus higher molecular weight compounds), and soil physics. An improved generation of soil carbon turnover models should account for the vertical stratification of soils. The explicit incorporation of ^{13}C and ^{14}C would permit the use of isotopic datasets for model testing and validation. Model-data integration as an iterative process will be an important way forward in improving both models and experimental designs.

Perspectives: research questions and approaches

In a general discussion the following issues were identified to be of major importance for future developments in the field:

• the plant-soil C transfer, as related to plant C allocation and below-ground C partitioning, in relation to the nitrogen cycle, soil and vegetation type, and phenology, and as affected by changing environmental conditions

• soil C turnover, in particular effects the quality and quantity of soil C input (litter, exudates, DOC, DIC) on decomposition and mechanisms of stabilization and destabilization (aggregates, priming), including aspects of soil type, vegetation type, and the N cycle

• the role of biota for SOM pools and fluxes, including effects of different functional groups (e.g. fungi/bacteria, soil fauna)

• soil C models, particularly as concerns their suitability for climate change scenarios, separating physico-chemical from enzymatic processes; improved representation of SOM pools and isotopes, improved description of physico-chemical stabilization and the interface between ecophysiology (C allocation) and soil modules; representation of vertical heterogeneity and biotic interactions.

In breakout groups and a plenary discussion more specific research questions and promising approaches were elaborated, targeted on the key topics of 'plant-soil C transfer', 'the role of soil biota' and 'SOM turnover'.

- **Plant - soil C transfer:** Major research questions are related to physiological mechanisms, as well as priming effects. Suitable approaches include 1) mesocosm studies investigating allocation patterns under different conditions (combined with isotopic labelling and considering also species effects; 2) long-term (growing season) isotope labelling combined with pulse labelling applied in mesocosms as well as ecosystems (long-term sites) undergoing long-term manipulation (fertilization, drought); studies on ecosystems should be concerted and ideally include different vegetation types, for improving the understanding of long-term dynamics. Generally, there is a need for more elaborate studies on root and mycorrhizal dynamics (growth, turnover) and on the influence of changing environments on the plant-soil C transfer. The latter should be approached combining different complementary methods, such as continuous and pulse labelling with ^{13}C and the use of radiocarbon.

- **Soil biota:** Major specific research questions are:

  1. What are the major controls and the interactive controls of soil biota on soil organic matter turnover?

  2. What is the potential of new concepts (e.g. of gradient approaches) for understanding the role of soil microbes on soil organic matter turnover?

  3. How can we link microbial processes at the small spatial and temporal scale to processes at the ecosystem level?

Experimental approaches to address these questions include 1) the manipulation of below-ground C allocation in simplified systems (mesocosms, keyspecies), 2) the assessment of microbial population dynamics in the field (for which the methodology would still need to be more developed), 3) the study of the role of biota for the stabilization and de-stabilization of SOM, as related to soil physics and changes in physical and chemical environment by biota.

- **SOM turnover:** Beyond the research questions concerning SOM turnover and its representation in models, as outlined above, a key question relates to the sensitivities and timescales of drivers effects on SOM decomposition and stabilization processes. To provide an overview on this topic an overview table will be compiled and form the basis for a synthesis paper. Furthermore, it would be helpful to obtain a synthesis emerging from juxtaposing models from different communities. Future approaches towards improving the understanding and model representation of physico-chemical aspects of SOM turnover will require a closer collaboration with specialists on aggregates and minerals, and need to consider the chemical quality of SOM fractions in relation to enzyme activity.

Follow-up activities

By exploring the frontiers of ongoing research and by harmonizing and prioritizing research question and approaches the exploratory workshop provided a basis for developing a number of follow-up activities. These were decided to include:

- A number of synthesis publications (including the topics of ‘the importance of biota for soil C turnover’, ‘drivers effects on SOM decomposition and stabilization processes’ and ‘A comparison of SOM turnover models from different communities’)
- An ESF research network
- A Marie Curie Training Network
- A EUROCORES proposal

For each of these planned activities a core group has been identified that will be responsible for its development and promotion.

4. Final Programme

Sunday, 20 September 2009

Afternoon	*Arrival*
19.00	*Informal Welcome and Dinner at Conference Venue (Hotel Geisler, Rinn)*

Monday, 21 September 2009

08.30-08.50	**Welcome by Convenor and Introduction to the Workshop** **Michael Bahn** (University of Innsbruck, Innsbruck, Austria)
08.50-09.10	**Presentation of the European Science Foundation (ESF)** **Giuseppe Scarascia-Mugnozza (Standing Committee for Life, Earth and Environmental Sciences - LESC)** (Standing Committee for Life, Earth and Environmental Sciences)
09.10-12.30	***Morning Session:*** **I Setting the stage: state of the art and open questions**
09.10-09.30	**Diel- to century-scale controls on soil CO_2 efflux. State of the art and open questions** **Eric Davidson** (Woods Hole Research Center, Falmouth, USA)
09.30-09.45	**Potentials and limitations of isotopic approaches to studying short- and long-term controls on soil respiratory fluxes** **Susan Trumbore** (University of California, Irvine, USA)
09.45-10.00	**What have we learned and can we still learn from manipulation experiments?** **Werner Borken** (University of Bayreuth, Bayreuth, Germany)
10.00-10.15	**Breaking up the black soil box through integration of new theories and observational constraints** **Markus Reichstein** (Max Planck Institute for Biogeochemistry, Jena, Germany)
10.15-10.30	**Discussion**
10.30-11.00	*Coffee / Tea Break*
	II Patterns and processes across ecosystems and biomes: evidence from emerging synthesis studies
11.00-11.15	**Diurnal response of soil respiration to photosynthetic activity** **Jorge Curiel Juste** (University of Barcelona, Barcelona, Spain)
11.15-11.30	**Time lag between photosynthesis and CO_2 efflux from soil** **Yakov Kuzyakov** (University of Bayreuth, Bayreuth, Germany)
11.30-11.45	**Understanding CO_2 efflux and CO_2 production: do we need to look deeper into the soil?** **Rodrigo Vargas** (University of California, Berkeley, USA)
	III Unraveling mechanisms with novel experimental approaches
11.45-12.00	**Novel insights from pulse-labelling experiments in a forest ecosystem**

Peter Högberg (Swedish University of Agricultural Sciences, Umeå, Sweden)

12.00-12.15	**Diel to seasonal soil respiration patterns: plant and microbial source contributions inferred from radiocarbon analyses** **Mariah Carbone** (University of California, Santa Barbara, USA)
12.15-12.30	**Short-term variations of $\delta^{13}C$ of organic matter and respired CO_2 in the plant – soil system: observed patterns and underlying mechanisms** **Arthur Gessler** (University of Freiburg, Freiburg, Germany)
12.30-12.45	**Discussion**
12.45-14.15	*Lunch*
14.15-18.00	***Afternoon Session:***
14.15-14.30	**On the importance of fresh C supply for microbial activity and SOM stability** **Sébastien Fontaine** (Institut National de la Recherche Agronomique, Clermont-Ferrand, France)
	IV Defining the baseline for a new generation of models
14.30-14.45	**Requirements for a conceptual framework integrating flux-based- and SOM turnover models: a flux-based perspective** **Ivan Janssens** (University of Antwerp, Wilrijk, Belgium)
14.45-15.00	**Requirements for a conceptual framework integrating flux-based- and SOM turnover models: a SOM-based perspective** **Pete Smith** (University of Aberdeen, Aberdeen, UK)
15.00-16.00	**Breakout groups** (corresponding to tasks 1-3) General discussion on issues emerging from the short lectures Definition of tasks and members of three breakout groups
16.00-16.30	*Coffee / Tea Break*
16.30-18.00	**Work in breakout groups**
19.00	*Dinner*
20.30-21.30	***Poster session*** (for list of posters cf. below)

Tuesday, 22 September 2009

08.30-12.30	***Morning Session***
08.30-10.30	**Continuation of work in breakout groups**
10.30-11.00	*Coffee / Tea Break*
11.00-11.30	**Continuation of work in breakout groups**
11.30-12.30	**Plenary presentation and discussion of first reports of the breakout groups**
12.30-14.00	*Lunch*
14.00-18.00	***Afternoon Session***
14.00-15.00	**Poster session**

15.00-16.00	**Continuation of work in breakout groups**
16.00-16.30	*Coffee / Tea Break*
16.30-18.30	**Synthesis** **Plenary presentation and discussion** of final reports of the breakout groups; Identification and general agreement on gaps and approaches required for making major progress in the field, incl. 1) data coverage and analysis, 2) targeted and concerted experimental approaches, 3) a conceptual model framework representing processes across a range of spatial and temporal scales
19.00	*Dinner*

Wednesday, 23 September 2009

08.30-11.15	***Morning Session:*** **Planning of follow-up research activities and collaborative actions** Discussion on targeted and concerted experimental approaches and possibilities of realizing collaborative actions, including joint research activities and synthesis publications
08.30-9.45	Discussion in breakout groups
09.45-11.00	Plenary discussion
11.00-11.15	Conclusion
11.15	***End of Workshop***

Subsequent to the ESF exploratory workshop the **COST Action ES806 (SIBAE) workshop on "Application of stable isotopes for studying and modelling soil respiration and soil organic matter cycling"** took place at the same venue from 23 September 2 pm - 25 September 2009 1 pm. At this back-to-back workshop the main results of the ESF exploratory workshop were briefly presented and discussed.

Poster contributions

Bahn M, Schmitt M, Siegwolf R, Richter A, Brüggemann N: Rapid transfer and respiratory use of photoassimilates in the plant-soil system of a mountain grassland

Carbone MS, Williams AP, Still CJ: Plant and microbial contributions to pine forest soil respiration: moisture controls in a Mediterranean climate

Curiel Yuste J, Mattana S, Estiarte M, Ogaya R, Sardans J, Penuelas J: Climate-induced shifts on microbial community structure and functionality on two Mediterranean ecotypes

Dalibor J, Pavelka M, Macku J, Havrankova K, Marek MV: Carbon stock changes in the forest soils under warming

Ekblad A., Hagedorn F., Larsson M., Wipf S: Determination of soil respiration rates and $\delta^{13}C$ in situ using a spectroscopic Picarro G1101-i instrument.

Plain C, Dannoura M, Ngao J, Parent F, Bakker M, Zeller B, Damesin C, Loustau D, Epron D: Tracing the transfer of recently assimilated carbon into the soil after in situ $^{13}CO_2$ pulse labelling of trees.

Heinemeyer A, Croft S, Platts P, Lomas MR, Foereid B: Modelling carbon dynamics in the organo-mineral soil continuum – considering our gaps in correctly representing hydrology, litter cohorts, soil mixing and SOM dynamics

Heinemeyer A, Subke J-A, Wilkinson M, Morison J, Ineson P: The 'overflow tap' theory: linking NPP to forest soil carbon dynamics and mycorrhizas

Kutsch WL, Persson T, Schrumpf M, Moyano FE, Mund M, Andersson S, Schulze ED: Heterotrophic soil respiration and soil carbon dynamics in the deciduous Hainich forest obtained by three approaches

Liski J, Karhu K, Kitunen V, Hämäläinen K, Vanhala P, Jungner H, Oinonen M, Sonninen E, Tuomi M, Spetz P, Fritze H: Temperature sensitivity of soil carbon fractions in boreal forest soil

Misson L, Battut J, Rocheteau A, Rodriguez R: Effect of extreme drought on soil CO_2 flux in a Quercus ilex forest

Pumpanen J, Rasilo T, Lepistö T, Heinonsalo J, Ilvesniemi H: Effects of clear cutting on soil C pool and CO_2 fluxes from forest soil

Rodeghiero M, Hakkenberg R, Churkina G, Cescatti A, Scholten T: Forest soil CO_2 efflux correlates with nitrogen content of decomposing litter layers

Subke J-A, Voke N, Leronni V, Garnett M, Ineson P: Evidence for priming of old and fresh soil organic matter in a girdling experiment in a temperate coniferous forest

Vargas R, Baldocchi D, Bahn M, Hanson P, Pumpanen J, Yang B: A multiscale analysis of the influence of GPP on soil CO2 efflux at multiple vegetation types

Wingate L, Ogée J: The impact of soil micro-organisms on the diurnal and seasonal $\delta^{18}O$ signals of ecosystem CO_2 exchange

5. Statistical information on participants

	No. (%) of participants
Countries of origin	
Austria	2 (6.7 %)
Belgium	1 (3.3 %)
Czech Republic	1 (3.3 %)
Finland	2 (6.7 %)
France	5 (16.7%)
Germany	6 (20.0 %)
Italy	1 (3.3 %)
Spain	1 (3.3 %)
Sweden	2 (6.7 %)
Switzerland	1 (3.3 %)
UK	4 (13.3 %)
USA	4 (13.3 %)
Gender	
Female	3 (10 %)
Male	27 (90%)
Age structure	
Advanced Scientists	19 (63.3 %)
Young Scientists [(1)]	11 (36.7 %)

[(1)] Ph.D./ Dr. degree since less than 10 years

6. Final list of participants

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