Research needs for terrestrial mitigation

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Monitoring, Reporting and Verification systems for Carbon in Soils and Vegetation in African, Caribbean and Pacific countries

Edited by

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FOREWORD

Improved terrestrial carbon management offers tremendous potential for climate change mitigation and, in many cases, there are associated co-benefits such as increased productivity, resilience, and biodiversity. It is expected that governments will agree to incentives for improved management of some forms of terrestrial carbon in developing countries, including maintaining existing carbon and creating new carbon in agriculture, forestry and other land-uses. Across a wide range of geographic scales and land classes, there is a need for a coherent, integrated information base for effective land management practices that produce real increases in sequestration together with real reductions in greenhouse gas (GHG) emissions from terrestrial sources, and transparent, consistent, and comparable quantification of changes in carbon stocks.

Maximizing terrestrial carbon sequestration while minimizing emissions, then documenting and rewarding outcomes requires the ability to deliver the following functions:

1) Estimating the total biophysical and feasible carbon mitigation potential (through avoided emissions and sequestration) for all land categories;
2) Measuring and monitoring terrestrial carbon for different land classes at multiple scales (including aggregated global estimates);
3) Setting reference emission and sequestration levels and complying with standards.
4) Building national capacities for monitoring, reporting and verification (MRV) of the emission and sequestration levels.

In the frame of the United Nations Framework Convention on Climate Change (UNFCCC) negotiations, the debate on reductions of GHG emissions was mainly focused to deforestation and forest degradation issues (REDD+ mechanism under discussion), but recent developments aim to include other land-use change classes in the estimates of the mitigation potential. The REDD sourcebook has already detailed the best practices for estimating the stocks and changes of carbon in the tropical forests, with a strong JRC input. A full Roadmap for Terrestrial Carbon Science has been compiled by the Terrestrial Carbon Group and details the way forward towards implementing such a research agenda.

For the Joint Research Centre (JRC), as a service of the European Commission, the main role will be to deliver the main functions listed above to the other services of the Commission in charge of the political negotiation and the projects' implementation and to facilitate the establishment of the necessary networks of scientists able to provide reliable decision-aid tools. In order to achieve this there is the need to join into major existing initiatives, like the "Global research alliance on agricultural greenhouse gases", the Terrestrial Carbon Group, the GEF Carbon Benefits Project, the UN-REDD and others. At the same time a specific JRC working group is being established, pooling together scientists of the JRC working on Terrestrial Carbon Science.

The final deliverables of this activity should be:

- Process-level understanding of carbon dynamics and mitigation potential
- Scientific research base for alternative management practices
- Feasible accounting tools for all lands and carbon pools (including all GHGs)
- Components of a tiered global information system
- Pathways to establishing national accounting systems that reflect country circumstances
- Harmonization of reporting guidance across scales and sectors

Based on this note, the JRC has organised on the 26th January 2011 a one-day discussion with Directorates-General (DGs) partners (CLIMA, DEVCO, ENTR, ENV, AGRI), interested Member States and selected experts in order to refine its research agenda on these issues.

The current report includes the scientific presentations delivered by external experts and JRC scientists, the needs of the policy-DGs in terms of information for multilateral environmental agreements, project implementation and general understanding of the carbon cycle. In particular, detailed information was provided on (i) the main regions of priority, (ii) the nature of the work (science-oriented or focused to international negotiations), (iii) depth of the information level to put in place, (iv) the nature of human activities to include in the MRV systems (forestry, agriculture, other anthropic areas, and natural areas). Finally the report draws the main conclusions of the meeting.

EXECUTIVE SUMMARY

In January 2011, the Institute for Environment and Sustainability of the Joint Research Centre organized an inter-service meeting on “Monitoring, Reporting and Verification systems for carbon in soils and vegetation in African, Caribbean and Pacific (ACP) countries” with the objective of refining its long-term research agenda in that domain. This was achieved in the light of the needs of the Directorates-General involved in the development and environment policies namely DEVCO, ENV, CLIMA, ENTR, RTD and AGRI as well as of the recent evolution of the UNFCCC negotiations.

This report encompasses the proceedings of the meeting together with the conclusions and recommendations to JRC work program stated by the invited experts and policy-makers from the different relevant DGs. The presentations given during the meeting and the final report are also available on the ACP Observatory website (*http://acpobservatory.jrc.ec.europa.eu/redd.php*).

ACP countries have a high carbon sequestration potential, mainly in agriculture, avoided deforestation and land use change management. The promotion of sustainable land management (SLM) practices can help to restore soil organic carbon stocks and to create new carbon sinks, thereby increasing carbon sequestration. The regions of ACP countries where the combination of climate, land use type and soil type show a high potential of mitigation need to be identified in order to target the most effective areas of implementation.

Some limitations to soil carbon sequestration were discussed during the meeting. Firstly, soil carbon stocks are of finite size and the potential for more sequestration should always be questioned. Secondly, soil carbon cycle is slow compared with carbon cycle in biomass which implies that both short and long-time scale MRV systems be developed. Thirdly, carbon sequestration reversibility raised a concern about the time-frame for measures implementation and compliance with emission levels.

Regarding MRV systems, hyperspectral techniques for monitoring and verifying soil organic stocks in croplands were presented and showed promising results. Other measurement techniques exist along with analytical solutions that are being developed for field carbon measurement, monitoring and verification. Overall, it appears that no MRV system is currently ready for implementation. This can be partly explained by the complexity of carbon dynamics related to land use and climate change, either in soil and biomass. It was however emphasized that soil monitoring community has a lot to learn from forest monitoring community.

The link between deforestation and agriculture was highlighted during the meeting. It is clear that MRV systems should be established not only for forestry matters but also for agriculture, thus working beyond the focus of REDD program. Agriculture mitigation is in fact a severe issue that needs to be addressed with the same attention as deforestation or forest degradation. The absence of a UN program similar to REDD and supporting climate change mitigation in agriculture was questioned.

The understanding and monitoring of REDD activities at a strategic and at an operational level was underlined and initiated a fruitful discussion. The strategic approach concerns national policies and compliance with international commitments. Monitoring at this level requires accurate data on carbon emissions, land use change, etc. Measurements are expensive but necessary to obtain a reliable national database. Once established, the latter may help setting reference levels of emissions upon which incentive mechanisms could be developed. Regarding the carbon market related to sequestration practices, the principle of additionality was highlighted. Incentives should be delivered only for projects that actually increase carbon stocks/ avoid carbon losses. Practices that allow carbon levels to remain constant shouldn’t be awarded. At this stage of UN-REDD program, the financial support to smallholder farmers and foresters remains unclear and uncertain. The compliance with voluntary forest and carbon certification schemes was highlighted as an alternative to national policy-related incentives that may require more time to be fully established. In addition, it was mentioned that since climate change and food security issues are closely related, budgets should be combined to tackle carbon emission issues. As for the operational level, it targets implementation on the ground, including assurance and enforcement at local/project/ programme scale. Monitoring requires less accurate data than at the strategic level and it could be based on proxies for which information are available at reasonable cost. Since ACP countries have high expectations regarding the amount of money that could be delivered by UN-REDD program, the establishment of an equitable incentive mechanism is necessary to encourage the implementation of land management measures in line with REDD objectives. The need to prioritize carbon sequestration techniques that address food security was highlighted by different attendees. It was also agreed that the focus should be on projects highly relevant at country level, bearing in mind both financial and technical national resources. One should also remember that social context may hinder the implementation of beneficial measures. The full understanding of REDD program and the key issues it addresses by smallholder farmers and foresters is of major importance to get them involved. In addition, elite capture of money in developing countries is a substantial problem that must be taken into account and prevented when possible.

The possibility to promote and put in place SLM practices disregarding the lack of knowledge on carbon emission levels was arisen. As a matter of fact, any measure implemented now allows avoiding or limiting degradation and would therefore reduce intervention costs in the future. However, incentives/additional income must be offered to those willing to act.

In conclusion, UN-REDD objectives together with carbon sequestration in agricultural land in ACP countries will be met if knowledge gaps are identified and research on MRV systems is carried on. Moreover, the transfer of scientific knowledge to policy guidance and thereafter to implementation must be ensured by improving communication between all stakeholders. Also, the share of data acquired by different working groups and partnership throughout ACP countries should be facilitated. In few words, there is an urgent need for capacity building from both institutional and technical viewpoint.

Attendees agreed that JRC could co-ordinate the work and bring partner countries together.

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LIST OF ACRONYMS

ACP: African, Caribbean and Pacific countries

AFOLU: Greenhouse gas in Agriculture, Forestry and Other Land Uses

ALOS: Advanced Land Observing Satellite

ASCII: American Standard Code for Information Interchange

CCX: Chicago Climate Exchange

CBD: Convention on Biological Diversity

CBP: Carbon Benefits Project

CDM: Clean Development Mechanism (under the Kyoto Protocol)

CEC: Cation Exchange Capacity

CEOS: Committee on Earth Observation Satellites

CER: Certified Emission Reduction

COP: Conference of Parties (of the United Nations Framework Convention on Climate Change)

CSU: Colorado State University

DEVCO: EuropeAid Development and Cooperation (Directorate-General of the European Commission)

DG: Directorate-General (of the European Commission)

DNDC: DeNitrification-DeComposition model

EEA: European Environment Agency

EIONET: European Environment Information and Observation Network

EROS: Earth Resources Observation Systems

ESA: European Space Agency

ESBN: European Soil Bureau Network

ESDAC: European Soil Data Centre

ESDB: European Soil Database

ESRI: Environmental Systems Research Institute, Inc., Redlands, California

ETM: Landsat Enhanced Thematic Mapper

ETS: European Trading System

EU: European Union

EUSIS: European Soil Information System

EX-ACT: *Ex Ante* Appraisal Carbon-balance Tool

FAO: Food and Agriculture Organization of the United Nations

FCPF: Forest Carbon Partnership Facility

FLEGT: Forest Law Enforcement, Governance and Trade

FP: Framework Program

FRA: global Forest Resources Assessment

FSCC: Forests Soil Coordinating Centre

GEF: Global Environment Facility (of the United Nations Development Program)

GEO: Group on Earth Observations

GHG: Greenhouse Gas

GLOSIS: Global Soil Information System

GLS: Global Land Survey

GMES: Global Monitoring for Environment and Security

GOFC-GOLD: Global Observation of Forest and Land Cover Dynamics

GWC: Green Water Credits

HRV: High Resolution Visible

HWSD: Harmonized World Soil Database

ICP Forest: International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests

IFN: Inventaire Forestier National

IIASA: International Institute for Apolied Systems Analysis.

INS: Inelastic Neutron Scattering

INSPIRE: Infrastructure for Spatial Information in Europe

IPCC: Intergovernmental Panel on Climate Change

ISRIC: International Soil Reference and Information Centre

JAXA: Japanese Aerospace Exploration Agency

JERS: Japanese Earth Resources Satellite

JRC: Joint Research Centre of the European Commission

lCER: long-term Certified Emission Reduction

LIBS: Laser-Induced Breakdown Spectroscopy

LSU: Landscape Units

LUCAS: Land Use/ Cover Area frame Statistical Survey

LULUCF: Land Use, Land Use Change and Forestry

MDG: Millennium Development Goals

M & E: Monitoring and Evaluation

MMU: Minimum Mapping Unit

MRV: Monitoring, Reporting and Verification

NAMAs: Nationally Appropriate Mitigation Actions

NUTS: Nomenclature of Territorial Units for Statistics

OC: Organic Carbon

PALSAR: Phased Array L-band Synthetic Aperture Radar

PES: Payment for Environmental Services

QA/QC: Quality Assurance/Quality Control

RMP: Recommended Management Practices

RMSE: Root Mean Square Error

RMSEP: Root Mean Square Error of Prediction

RS: Remote Sensing

RSS: Remote Sensing Survey

SAR: Synthetic Aperture Radar

SBSTA: Subsidiary Body for Scientific and Technological Advice (of the United Nations Framework Convention on Climate Change)

SDSU: South Dakota State University

SGDBE: Soil Geographical Database of Europe

SLM: Sustainable Land Management

SMN: Soil Monitoring Network

SOC: Soil Organic Carbon

SOM: Soil Organic Matter

SPOT: Satellite Pour l'Observation de la Terre (Earth Observation Satellites)

tCER: temporary Certified Emission Reduction

TM: Landsat Thematic Mapper

UCL: Catholic University of Louvain (Louvain-la-Neuve, Belgium)

UNCBD: United Nations Convention on Biological Diversity

UNCCD: United Nations Convention to Combat Desertification

UNDP: United Nations Development Program

UNFCCC: United Nations Framework Convention on Climate Change

UN-REDD: The United Nations collaborative program on Reducing Emissions from Deforestation and Forest Degradation in developing countries

VCS: Verified Carbon Standard (initially named Voluntary Carbon Standard)

VNIR: Visible and Near Infra-Red

VPA: Voluntary Partnership Agreements

GENERAL OBJECTIVES AND RESEARCH NEEDS

The JRC activities related to carbon issues

F. Achard, F. Bampa, A. Brink, D. de Brogniez, O. Léo, P. Mayaux and L. Montanarella[1]

The work programme of the JRC is implemented by research actions. A number of them contribute to the understanding of the role of the terrestrial carbon pool in climate change, but a single coordinated approach is lacking. This has been fully recognized and in the recent re-organization of the JRC activities according to thematic areas, a specific thematic area has been created addressing the low carbon economy.

The meeting held in Brussels in January 2011 on the "MRV systems for carbon in soils and vegetation in ACP countries" aimed at the development of a coherent work program on terrestrial carbon within the JRC. The meeting was inserted within the Thematic Program "ACP-Observatory" coordinating the JRC activities in developing countries.

A detailed description of the objectives of each action addressing the terrestrial carbon pool is available at http://ies.jrc.ec.europa.eu/index.php?page=research-actions. In addition, a complete description of the actions working on ACP countries is also available at http://acpobservatory.jrc.ec.europa.eu/. Below a brief description of five relevant actions is given.

Soil Data and Information Systems (SOIL)

The SOIL Action is aiming at the development of policy relevant soil data and information systems. It has established the European Soil Data Centre (ESDAC) as a single focal point for all soil data and information in Europe. The SOIL Action develops procedures and methods for data collection, quality assessment and control, data management and storage, data distribution to Commission and external users. It also carries out research on and develops advanced modelling techniques, indicators and scenario analyses in relation to the major threats to soil such as the decline of soil organic matter. In addition, it has as an objective the extension of the coverage of the European Soil Information System (EUSIS) towards a fully operational Global Soil Information System (GLOSIS), providing relevant soil information for the implementation of multilateral environmental agreements, like UNFCCC, CBD and UNCCD.
http://ies.jrc.ec.europa.eu/index.php?page=action-22004

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Global Forest Resources Monitoring (TREES-3)

The TREES-3 Action provides quantitative measurements of changes in forest resources relevant to the EU policies related to global environmental and forestry issues. The geographical focus is on forests in the tropics and in boreal (Russian Federation) region. The work generates regional forest maps, track areas of rapid forest change and produce estimates of forest cover change for the current and previous decades (from 1990 up to 2010).
http://ies.jrc.ec.europa.eu/index.php?page=action-42003

Monitoring Natural Resources for Development cooperation (MONDE)

The MONDE Action is establishing dedicated monitoring techniques for promoting the sustainable management of natural resources mainly in ACP countries. Particular attention is paid to land cover and land use dynamics, fresh water availability and management, land degradation, fire dynamics and regimes and the assessment of, and threats to, biodiversity, especially in protected areas and in specific ecosystems. Tools combining satellite data, advanced geospatial analysis and socio-economic models are shared with Commission services and ACP countries in charge of sustainable management of natural resources and environmental protection.
http://ies.jrc.ec.europa.eu/index.php?page=action-42001

Food Security Assessment (FOODSEC)

The FOODSEC action has developed a system for regional monitoring and forecasting of food security in various parts of the world. Satellite data and Global Meteorological Models are regularly received and processed and advanced tools and models for crop yield monitoring and forecasting have been developed. All the activities are done in close collaboration with European partners and the United Nations Food and Agriculture Organisation (FAO).
http://ies.jrc.ec.europa.eu/the-institute/units/monitoring-agricultural-resources-unit/foodsec-action.html

Biosphere, Climate and Human interactions (BIOCLIM)

The BioClim Action focuses on the effectiveness of EU and global policies that potentially impact the cycling of carbon and nitrogen compounds between the atmosphere and the biosphere by: (i) providing scientific and technical support for the LULUCF (Land Use, Land Use Change and Forestry) and agricultural sectors of the European Union Greenhouse Gas Inventory system, (ii) supporting EU and global long term monitoring of greenhouse gas concentrations and fluxes through measurement programmes.
http://ies.jrc.ec.europa.eu/the-institute/units/climate-change/bioclim-action.html

Monitoring, Reporting and Verification systems for Carbon in Soils and Vegetation in African, Caribbean and Pacific countries: A DEVCO view

P. Mikos and D. Radcliffe[1]

In recent years, hunger and malnutrition have increased; in 2010, over 1 billion people are considered to be food insecure. Food insecurity affects human development, social and political stability, and progress towards achieving the Millennium Development Goals (MDGs). Fragile states in particular encounter severe difficulties in achieving MDG 1 –eradicating extreme poverty and hunger.

In 2010 the 'EU Policy Framework to assist developing countries in addressing food security challenges (COM 2010/127) was approved by the EU Council. This policy addresses food security in both rural and urban contexts across the internationally recognised four pillars by: 1)increasing availability of food; 2) improving access to food; 3) improving nutritional
adequacy of food intake; and 4) enhancing crisis prevention and management. It is based on the Rome principles on food security. In particular it recognises that food security strategies need be country-owned and country-specific, elaborating an appropriate balance between support to national production and covering food needs through trade.

Most of the poor and hungry in the world live in rural areas, where agriculture – including crops, livestock, fisheries and forestry - forms the main economic activity. Small-scale farming is dominant: about 85% of farmers in developing countries produce on less than 2 hectares of land. Mixed crop/livestock smallholding systems produce about half of the world's food. Therefore, sustainable small-scale food production should be the focus of EU assistance to increase availability of food in developing countries. It has multiple effects of enhancing incomes and resilience for rural producers, making food available for consumers, and maintaining or enhancing environmental quality. When supporting small-scale agriculture EU assistance should prioritise intensification approaches that are sustainable and ecologically efficient, respecting the diverse functions of agriculture.

Sustainable management of natural resources underpins agricultural production systems in the medium to long term. Food security, adaptation and mitigation often benefit from similar policies and technical measures and, while trade –offs may sometimes need to be made there are opportunities for

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triple win scenarios in which agricultural production is enhanced, adaptation capacity strengthened and net GHG emissions reduced.

Achieving the agreed targets for 2020 and 2050 and keeping projected temperature increases within 2°C by 2100 will require a concerted global effort across all sectors of the economy. If fundamental climate change adaptation and mitigation goals are to be met, the mitigation potential from agriculture – that together with land use changes accounts for over 30 % of the global GHG emissions – has to be included in the international negotiations towards a follow-up of the Kyoto Protocol.

Given that most of the global potential for agricultural mitigation lies in developing countries, the role that especially small scale producers can potentially play in achieving global targets should be recognized, and a process to create a realistic and fair set of incentives to reward developing country farmers for adopting carbon conserving practices should be initiated. This would be additional to the strong case that has to be made for increasing the support to developing countries for adaptation to climate change, making sure that adaptation activities are integrated into sector strategies and general development strategies, and not established as a separate programme.

For a development-led approach to GHG mitigation through changes in land use or agricultural practices to be successful, a clear understanding of benefits, synergies and trade-offs in specific locations is needed. Avoided emissions or sequestered carbon should be seen as a public good to which farmers or forest dwellers contribute. MRV systems to monitor changes in carbon stocks need to be reliable, but also cost effective and easy to apply in developing countries. Methodology should be linked to international standards. There may also be opportunities to link MRV of carbon stocks to the monitoring of development outcomes. Most importantly, any system of incentives must be equitable and genuinely benefit smallholder farmers or forest dwellers, who may be poor, have insecure land rights, and few economic opportunities. It may be necessary to regulate incentives to prevent elite capture. More work is needed to assess if a market based or public subsidy system, or a combination of the two, would be most appropriate.

Capacity-building needs in developing countries for MRV national systems

P. Mayaux[1]

Introduction

This short paper aims at describing the demanding task of building the human capacities and transferring the technological know-how to the African, Caribbean and Pacific countries for developing long-term monitoring systems of terrestrial carbon. In the future REDD mechanism, developing countries will indeed have to setup operational monitoring, reporting and verification systems of their natural carbon stocks, that meets the Best Practices of the International Panel on Climate Change (IPCC), i.e. (i) temporal consistency of the measurements, (ii) transparency of the estimates, (iii) comparability of the methods, (iv) completeness of all the carbon pools, and (v) accuracy documentation (Herold, 2009).

These pages are largely inspired by several studies on the evaluation of capacity-building needs and research needs already conducted in different contexts: Herold, 2009; Terrestrial Carbon Group, 2010. We will in these pages successively describe:

- the information gaps for setting up national MRV systems
- the geographic identification of the gaps
- the target population of capacity-building activities
- the possible training strategies.

Information components to reinforce

Before identifying geographical gaps and defining a strategy for building on existing capacities, it is important to discover the overall knowledge gaps for providing comprehensive, robust and transparent accounting systems. The following tables are extracted from the report of the Terrestrial Carbon Group and clearly determine the current state-of-the-art from the purely scientific estimates of the carbon pools to the reporting systems. The second table details this full chain by type of land-use class (forests, croplands, grasslands/drylands, and wetlands).

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Table 1. What we know and priority research needs

	1. Carbon dyamics	2. Alternative Management	3. Accounting Tools	4. Global system components	5. National Accounting Systems	6. Reporting Guidance
What is already known	• Solid understanding of factors and processes controlling spatially-variable terrestrial carbon stocks and fluxes. • General predictions for effects of changing climatic / environmental conditions on carbon dynamics.	• Wide range of management practices can effectively maintain / enhance terrestrial carbon mitigation.	• Appropriate field measurements, remote sensing, conversion equations, and models can be combined to estimate C stocks and changes • Greatest experience in above-ground biomass and in homogeneous landscapes	• National reports, commercial / academic assessments, global databases, and other existing resources are building blocks for national systems. • Multilateral agencies, research institutions, and others are working on data improvement, integration, and accessibility.	• National systems can estimate mitigation potential for major land classes and actual emissions / sequestration by drawing on international guidance, available tools, and existing data systems.	• Scope and clarity of reporting guidance from IPCC, voluntary markets improving with experience and scientific advancement.
Priority research needs	• Spatially-resolved prediction of carbon dynamics. • Effects of changing climate on carbon dynamics in specific land classes and regions.	• Synthesized, accessible, geographically-relevant scientific research base for net effects of alternative practices (including complex landscapes, variable land management). • Accurate, spatially-resolved data for land cover, C density, and land management. • Understanding of land use change drivers. • Extension activities, incentives, and infrastructure.	• Labor- and cost-saving field measurement approaches. • Improved remote sensing interpretation methods. • Data-gathering and model adaptation / validation for underrepresented land classes and regions. • Networks of permanent benchmark monitoring sites. • Regionally-relevant conversion factors and allometric equations for all carbon pools and land classes. • Continuity of key remote sensors. • Convergence / crosswalking of models.	• Improved, accessible global / regional datasets (eg, soil mapping, CO2 budgets, conversion equations). • Modelling frameworks to build spatially-comprehensive, long-time series datasets from multi-scale, multitemporal field and remote sensing observations. • Down-scaled estimates of mitigation potential. • Standardized data-gathering, analytical methods, and land classification systems.	• Cost-effective, regionally-relevant, internationally-compatible methods. • Country-specific sampling designs for all major land classes. • Coherent guidance and technical assistance. • Technical transfer (north-south; south-south). • Adequate resources and capacity for consistent, long-term operation. • Modelling / crosswalking to integrate diverse datasets. • Combining field measurement, remote sensing, and modelling.	• Harmonized guidance and methodologies across scales and sectors. • Consistent terminology, definitions, and classifications. • Accelerated methodology development / acceptance (especially for non-forest land classes). • Continual review, updating, approval of IPCC guidelines. • Mandates for coordinating and technical advisory functions.

Table 2. Research needs for major land classes

	Carbon dynamics	Alternative Management	Accounting Tools	Global system components	National accounting systems	Reporting guidance
Forests	Non-biomass carbon. Fire regimes.	Outcomes under specific conditions (eg, complex landscapes, tropics).	Monitoring degradation. Regionally-relevant models.	Data sharing across scales and sectors.	All countries. Capacity for monitoring degradation.	Compatible terms, definitions and standards.
Croplands	Partitioning to soil carbon pools. Variability with depth.	Outcomes under integrated cropping, agroforestry. Residence times for soil carbon pools.	Regionally-relevant field data and models.	Data sharing across scales and sectors.	Regional conversion equations. Field data.	Methodology development / approval. Compatible terms, definitions and standards.
Grasslands/ drylands	Soil carbon dynamics and sequestration rates. Fire regimes	Effects of grazing, fire management. Extent of sequestration, desertification, degradation, and conversion.	Regionally-relevant field data and models.	Integrated research and inventory data. Data sharing across scales and sectors.	Sampling designs. Regional conversion equations. Field data.	Methodology development / approval. Compatible terms, definitions and standards.
Wetlands/ Peatlands	Depth, density, decomposition. Controls on GHG emissions. Peatland subsidence.	Outcomes of rewetting under specific conditions. Peat extent, depth, conversion, drainage, and degradation.	Tools / methods to accurately inventory area and fluxes. Regionally relevant field data and models.	Integrated research and inventory data. Data sharing across scales and sectors.	Sampling designs. Regional conversion equations. Field data.	Methodology development / approval. Compatible terms, definitions and standards.

Robust knowledge base – incremental work needed

Existing knowledge base – additional coordinated research required

Growing knowledge base – more comprehensive research needed

Emerging knowledge base – significan research investment needed

Geographical location of the needs

Herold (2009) produced a synthesis of the countries with the largest capacity gaps in (i) deforestation monitoring, (ii) estimation of the carbon stocks, (iii) reporting of the Greenhouse Gases inventories. Very clearly, the African continent is the region where the capacity-building needs are the most obvious, as illustrated on Fig. 1. It explains why many programs (Forest Carbon Preparatory Facility, UN-REDD) put a major effort in this part of the world.

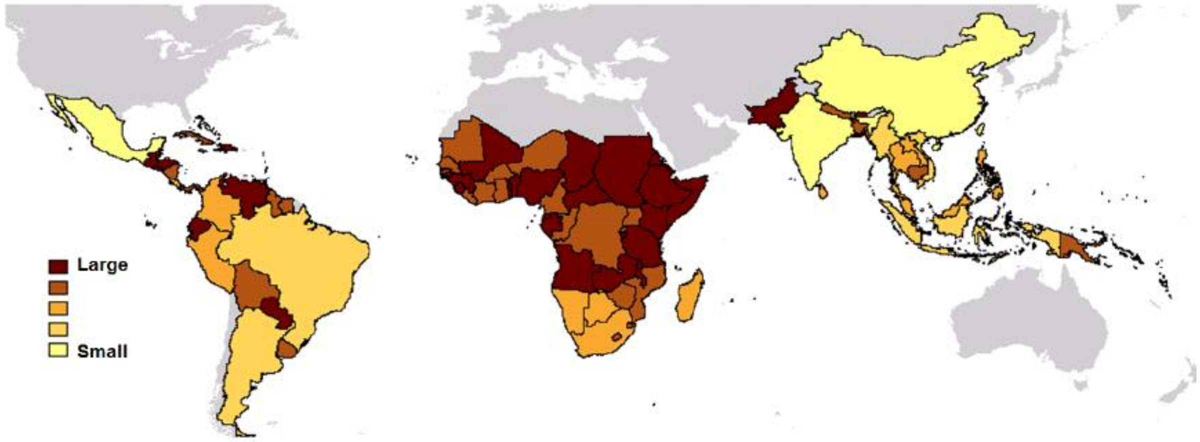

Figure 1. Spatial distribution of the capacity gap for different countries analyzed (from Herold, 2009).

The table 3 details the current availability of information in the two axes: forest area and forest carbon, emphasizing if the information is already produced internally by the national capacities.

Table 3. Summary of country capacities for monitoring forest area change and forest inventories for a selection of 30 countries. Extracted from Herold et al., 2009

		Forest Area change monitoring				
		No forest cover map	Forest cover map external	Multiple forest cover maps (external)	Forest cover maps before 2000 (internal)	Forest cover maps after 2000 (internal)
Forest inventory	No national forest inventory			Paraguay Tanzania	Congo Ecuador Nepal	Bolivia Colombia Malaysia
	One national forest inventory	Guyana CAR Gabon Nigeria	Zambia	Liberia	Ghana Panama	Costa Rica Brasil
	Multiple forest inventories (external)			DR Congo PNG		
	Forest inventories before 2000 (internal)		Cameroon Suriname	Madagascar	Laos	Indonesia Peru Vietnam
	Regular Forest inventories available after 2000 (internal)					India Mexico

Target population

As described in other chapters of this document, the MRV systems must answer to the following questions: (i) how the land-use areas do change (activity data), (ii) what is the carbon content of each specific class (emission factor), (iii) what is the overall impact of the national emissions of carbon (emission estimate). For each these questions, the capacities must be strengthened at national level (green boxes in Fig. 2).

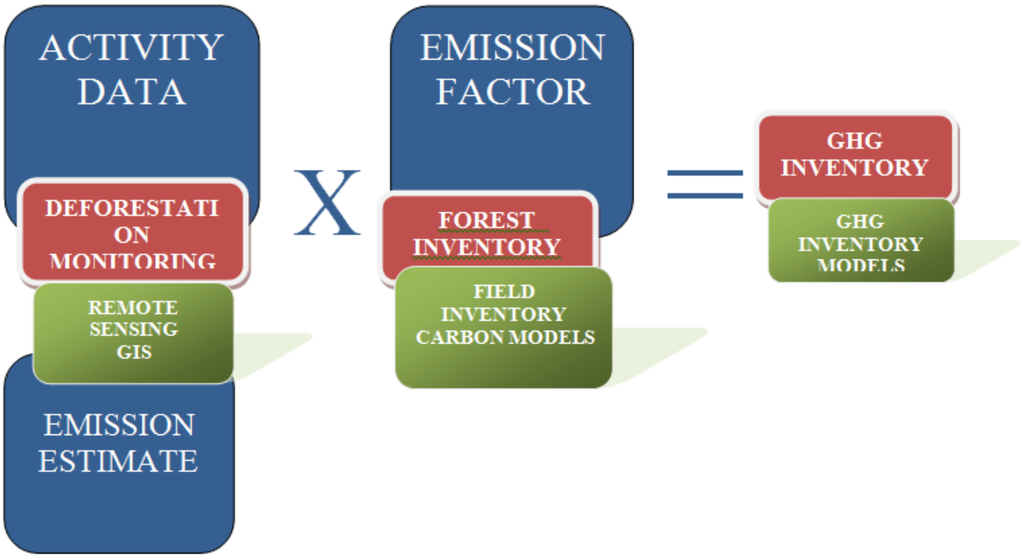

Figure 2. General scheme of emission estimate at national level, with the main activities to conduct (red boxes) and the thematic fields where the capacities have to be guaranteed (green boxes).

Different levels of capacities should be reinforced: (i) technicians involved in the day-to-day management of natural resources and in the implementation of the MRV systems, managers of natural resources involved in the planning and implementation of policies, high profile scientists for adapting scientific tools and methods to the African context.

Table 4. Summary of the capacity needs by profile and domain of intervention.

	Activity data	Emission factor	Emission estimate
Technicians	Remote Sensing / GIS (implementation – reasonable number)	Field inventories (high number)	
High profile specialists	Remote Sensing / GIS (design – limited number)	Sampling design, carbon models (limited number)	Integration (limited number

Moreover, the local communities should also be trained for using earth observation service into management problems solving and sustainable use of natural resources, in the phase of the implementation of REDD+.

Strategies of capacity-building

According to the profile of the professionals and the local context, the reinforcement of capacities should adopt different strategies:

- Creation of reinforcement of existing schools for technicians (forestry, fauna, rural development…) or in specific schools with a focus on Space-based technologies. In that respect, the role of regional schools, like the 'Ecole Régionale post-universitaire d'Aménagemement et de gestion intégrées des Forêts et Territoires tropicaux' (ERAIFT) in Kinshasa can be strengthened since economies of scale can be realised by joining efforts of countries with limited resources and similar issues and context. On the other hand, the African Union Commission desires to setup specialised Panafrican Universities. A MRV component could be included in the University dedicated to environmental monitoring
- Exchange with international teams (North-South or South-South) for training high level specialists able to design the national forest inventories (with the geospatial component) and GHG inventories.
- In the short term, existing and future projects can replace the current lack of training institutions with their own training activities, as shown in the following section.

An experience in Central Africa

The JRC has established a global deforestation monitoring system (see Achard et al., in this report) in collaboration with the FAO Forest Resource Assessment. In Central Africa, this study follows a previous estimate done in 2008 with the Université catholique de Louvain (UCL). The current study objectives were twofold. The first one was to deliver a valid estimate of complex forest dynamics at the national level. The second purpose was to enhance national capacity for monitoring, assessing and reporting on forests and land use changes.

National forest remote sensing involvement was considered by all parties as an essential dimension of the overall process. While several steps, such as image selection, pre-processing and automated classification were completed by the JRC and UCL team, 15 national experts were invited for a 2-week workshop to validate the automatic pre-interpretation for land cover mapping and forest change detection. In joint collaboration with the Forest Resources Assessment (FRA) 2010 remote sensing survey, this regional validation workshop was organized at the ERAIFT in October 2009 in Kinshasa (DRC). After 2 days of training, the experts have conduct in autonomy the validation for their own country and the results will be published in the State of the Forests 2010 (De Wasseige et al. 2011).

Figure 3. National experts and international team at the regional validation workshop in Kinshasa, 2009.

Conclusion

As already mentioned, the REDD+ mechanism represents a unique opportunity for improving the national capacities of forest services in terms of policy definition, implementation and monitoring. Indeed, the MRV systems and the development of field projects on the field require strong national authorities at central and decentralized levels. Although the details of the REDD+ are not well defined, a reliable monitoring system is fundamentally necessary for maintaining the economic value and the ecological services of tropical forests, at the benefit of local population. It means that forest monitoring systems must enlarged to other ecosystem services, like the conservation of biodiversity, the regulation of the water cycle, the provision of Non Timber Forest Products, and the timber production.

The challenges are huge, but the current capacities are weak. Donors should therefore concentrate in a concerted manner their efforts in building the capacities of national services, decentralized implementation agencies and local population.

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Why and how do MRV systems matter for REDD+ policy discussions?

M. Bucki[1]

MRV and reference levels

What can be achieved by 2020 in terms of accuracy and mapping resolution of MRV systems for forest cover, degradation, fragmentation and other ecosystem indicators will influence the setting of **Reference Levels**: For a performance based mechanism to deliver, there must be a reference level (i.e., a 'baseline') against which actual change in deforestation and degradation can be reliably contrasted so that:

- All developing forest countries that are or could plausibly be affected by deforestation and/or degradation can get significant incentives to prevent them. (inclusiveness)
- Participating countries can predict how much support they can expect for REDD+ activities and what they need to achieve in order to get this support (clear rules).
- Early action is rewarded. Strategic gaming of the system (overestimations) is prevented
- Overall emission reductions are maximised and secured over time (effectiveness), at the lowest overall cost (efficiency).
- The "net" effects of REDD+ actions are accounted only if they differ significantly from what would have occurred in the absence of these actions (additionality, no windfall credits): Efforts, rather than circumstances, must be rewarded (equity, fair benefit sharing).
- Cancun safeguards and principles are respected and promoted. Non carbon benefits are incentivised.
- Further reference levels reduce over time to motivate countries to continue decreasing their deforestation. Annual and short term fluctuations in deforestation rates are smoothed by averaging over period of 5 to 10 years (time consistency).

Managing complexity

In addition, REDD+ countries face a much broader and dynamic set of forest situations than LULUCF (Land use, land use change and forestry) countries in terms of natural resources (forest types, biodiversity value, precious minerals, fossil fuels), relative forest cover, economic relevance of agricultural and forest sectors, deforestation rates, capacities (including governance, enforcement,

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land tenure and forest information) and Human Development Index. Historical baselines can therefore not be used as a common denominator but at the same time methodologies and projections propping up forward-looking reference levels are extremely challenging: While “predictive” models can more or less anticipate where the next deforestation will take place (usually close to roads), they cannot tell when it will occur: this depends particularly on the price of agricultural, mining and forest commodities, which makes the link with drivers, such as global trade and food security. Deforestation and degradation are also affected by random events such as conflicts (which trigger migration), changes in currency parity and climate variations (which reduce or increase the risks of forest dieback and large-scale fires). All these factors should as well be explicitly taken into account in the design of reference levels, and integrated in MRV systems accordingly.

For conservation areas, where by definition not much should change in terms of forest carbon stocks and emissions, other types of incentives could be explored. Methods available and existing practices to map and monitor biodiversity, forest carbon and other aspects of sustainable management of forests should contribute to REDD+ information systems in order to help holistic decision-making on forest carbon sequestration, the conservation of forest biodiversity and the sustainable management of forests and ecosystem services. Measures should also support the sound and cost effective definition and achievement, of both climate change and biodiversity commitments of UNFCCC and UNCBD Parties, especially in areas where degradation, conservation or use of forests take place.

As to below ground biomass, it appears that no MRV system is currently ready for implementation although emissions can be very significant.

Adapting MRV systems to the broader REDD landscape, including agriculture

REDD+ provides an opportunity for climate protection and enhancing the livelihoods of farming and forest communities. It has become increasingly apparent that an understanding of the agricultural context of REDD+ projects is critical to success. Agriculture is a major driver of deforestation, and the fate of forests is often closely connected to the management of the agricultural landscapes in which they sit. The trajectory of agricultural development is a key determinant of the success of REDD+. Reciprocally, forest protection may increase agricultural emissions. When agriculture is effectively constrained from expanding into protected forests, one option for farmers facing increased demands is to intensify existing agriculture. However, agricultural intensification in the landscape can greatly increase emissions in the form of carbon (e.g., from intensive soil tillage or eliminating fallows) or the far more potent greenhouse gases (GHG) methane and nitrous oxide (e.g., from nitrogen fertilization or livestock wastes), thus reducing the net climate benefits accruing from forest conservation. The implication of the above analysis is that REDD+ mechanisms (and MRV systems) should be designed and implemented within a broader landscape frame.[2]

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[2] Making REAL(U) Right Harmonizing Agriculture, Forests and Rights in the Design of REDD+
Sara J. Scherr, Seth Shames, Courtney Wallace, Jeffrey Hatcher, Andy White, Peter Minang - EcoAgriculture Partners, Rights and Resources Initiative, World Agroforestry Centre.

Research needs for terrestrial mitigation

T. Havemann and C. Negra[1]

Introduction

This research note summarizes and provides an update for a report produced in April 2010 by the Terrestrial Carbon Group, entitled “Roadmap for Terrestrial Carbon Science: Research Needs for Carbon Management in Agriculture, Forestry and Other Land Uses.” That report assessed the scientific and technical advancements needed to support land-based mitigation of climate change and identified priority research needs to accelerate avoided emissions and sequestration of terrestrial carbon.

Our hope is that the previous report and this research note will stimulate discussion and action, leading to increased and improved research activity. At the end of this paper, we recommend priority actions for the JRC.

The context: Opportunities & challenges

There are existing and emerging financial incentives for land managers to adopt practices that contribute to climate change mitigation. Maximizing terrestrial carbon sequestration while minimizing greenhouse gas (GHG) emissions, then documenting and rewarding outcomes requires the ability to deliver the following functions (see Fig. 1):

1. Estimate the total biophysical and feasible potential for terrestrial mitigation (through avoided emissions and sequestration) for all lands;
2. Measure and monitor terrestrial carbon (based on land area and carbon density) for different land classes at multiple scales (and aggregate project-scale and national carbon accounting data to produce global estimates);
3. Set reference emission and sequestration levels and comply with standards.

In order to achieve the most effective and efficient net mitigation, there is a need for a coherent, integrated information base for effective land management practices that produce real results, and in a way that is transparent, consistent and comparable across space and time.

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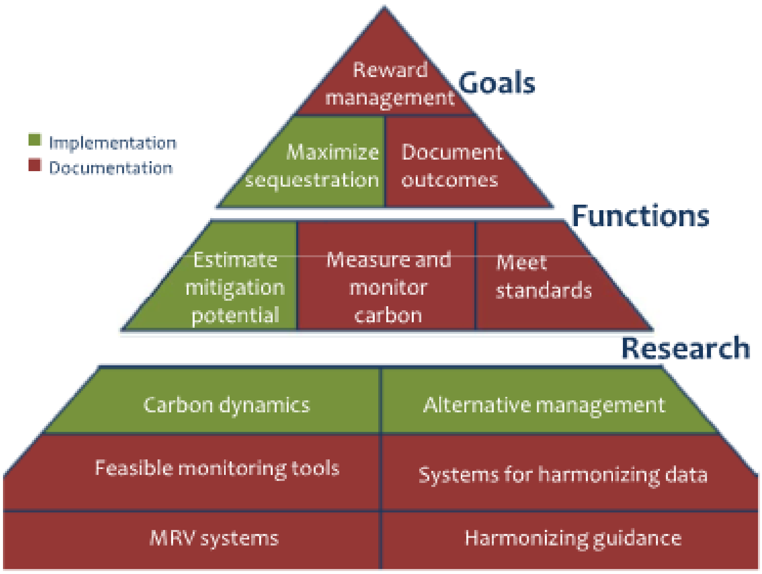


Figure 1. Goals, required functions and priority areas for implementing and documenting improved management of the world's terrestrial carbon.

Research needs: Six major categories

Six general categories encompass the scientific and technical research needs required to deliver essential functions. These are discussed below. Table 1 provides an overview of what is already known and priority research needs for all six categories. Table 2 summarizes research needs for four major land classes.

1. *Process-level understanding of carbon dynamics and mitigation potential*

What are the primary research needs?

In order to estimate mitigation potential in terrestrial ecosystems, it is necessary to understand the major biophysical processes that control carbon dynamics and GHG flux in soils and biomass. Greater understanding is needed for all land classes and carbon pools, however this need is greatest for grasslands, drylands, wetlands and peatlands and for non-biomass carbon pools (eg soil organic matter).

Primary research needs for croplands include partitioning to soil carbon pools over decadal time periods and variation in carbon quantity and vulnerability to decomposition with depth. For grasslands and drylands the research focus should be on synthesizing existing knowledge, particularly assessments of soil carbon behavior at various scales and under different influences (climate, land use, management). Wetlands and peatlands also require additional work to characterize major biophysical processes; peatlands in particular require greater research regarding how depth, density and decomposition affect emissions and sequestration. Forest systems are relatively well understood compared to other land classes. In general there is a need for improved estimates of mitigation potential of various land classes.

What can be done to meet research needs?

Major opportunities include:

- New research in understudied regions and land classes
- Integrating research activity to address whole landscapes
- Synthesizing findings from existing research base
- Improving estimation of biophysical sequestration potential

2. Scientific research base for alternative management practices

What are the primary research needs?

A wide range of land management practices have been shown to be effective at contributing to mitigation yet at more robust scientific research base is needed to enable shifts in management in all types of lands (including heterogeneous landscapes) by a range of land managers (e.g. agribusinesses, smallholders). While relatively well studied, more details on mixed forest systems and tracking of forest changes is required. Croplands have been well studied in certain regions, but field trials across an expanded geography is needed as well as further study of residence times for various soil carbon pools (i.e., how long carbon is retained in different pools) and exchange of GHG between soil and the atmosphere under different land management practices. For grassland and dryland systems, a greater understanding of the long-term impact of land management practices on sequestration is required along with improved information systems for changes in carbon. For peatlands and wetlands, a refined understanding of GHG emissions under current or alternative management practices is needed. A better understanding of peat extent and depth, land use conversion rates and degradation must complement this. Finally, in many countries, activity data needed for estimating historical and current emissions and sequestration is not spatially explicit.

What can be done to meet research needs?

Past efforts that have emphasized improving productivity (e.g. for timber, agricultural products) should be complemented by a focus on mitigation and sequestration. Opportunities include:

- Identifying areas of high terrestrial mitigation potential
- Identifying understudied regions
- Investigating mitigation potential associated with alternative management practices
- Expanding research to include alternative management for all land classes
- Operationalizing an integrated continuum view of landscapes
- Gathering and analyzing socio-economic data related to land use change drivers

- Fast-tracking scientific advancement to land managers

3. *Feasible accounting tools for all lands and carbon pools (including all GHGs)*

What are the primary research needs?

Appropriate measurement and monitoring methods are necessary to demonstrate that real, quantifiable, and comparable emission reductions and sequestrations take place. Data is collected and interpreted using a range of tools and methods such as field measurements, remote sensing, models to interpret data from sensors and models to interpret other data (including conversion and default equations). Improvements are required to all these tools and methods. More field data, of better quality, are required, particularly for underrepresented pools (i.e. other than aboveground biomass) and geographies. Although enormous advances have taken place in remote sensing technology, additional guidance and experience is necessary to determine how best to integrate different optical, laser and radar remote sensing technologies. Models to interpret data need to be adapted to places where they have not yet been validated, and to accommodate new types of data (e.g. from remote sensing). Further development of allometric equations is required, particularly for non-commercial plant species and specialized locations.

What can be done to meet research needs?

Enhancing measurement and monitoring capacity is a general requirement. Additionally, better data-sharing systems are required as well as more consistency around approaches. Specific opportunities include:

- Gathering field and activity data for underrepresented regions, land classes and carbon pools
- Developing new cost- and labor-saving measurement tools and methods
- Continuing to improve interpretation capacity for remote sensing
- Ensuring continuity of major satellites and promoting appropriate use of new remote sensing technologies
- Expanding coverage of conversion equations to all regions and types of carbon
- Adapting and verifying existing models to broader set of regions and data streams

4. *Components of a tiered global information system*

What are the primary research needs?

A tiered, global information framework is needed that can establish measurement protocols, integrate data generated through a variety of measurement approaches, and make information resources widely accessible. The major obstacles to date have been classification consistency for land use, and the type of information collected (since different countries and organizations collect data according to their needs).

What can be done to meet research needs?

Opportunities to build towards a tiered global information system by improving the consistency and comparability of data-gathering and estimation methods and datasets are:

- Standardizing data-gathering and land-cover classification
- Continuing improvements in soil mapping
- Integrating existing datasets
- Synthesizing diverse data through modeling
- Downscaling mitigation estimates
- Increasing accessibility and coverage of remote sensing and other mapping efforts
- Improving conversion and expansion factors
- Building common archives
- Improving coordination

5. Pathways to establishing national accounting systems that reflect country circumstances

What are the primary research needs?

National systems will be an essential component of a tiered, global accounting framework, producing and compiling data for incorporation into global estimates and for informing sub-national planning and implementation of improved terrestrial carbon management. Progress on national accounting systems is patchy – particularly when all land classes and GHG pools are considered. Improved national systems will require significant resource investments and increased coordination. Countries will use a different mix of tools, methods and sampling designs depending on their geographies and budgets. Not only must there be appropriate investment in establishing completely new systems in some countries, but also in ensuring that they continue to deliver required results.

What can be done to meet research needs?

Developed nations have a role to play in assisting developing countries to establish or expand infrastructure and expertise to collect and analyze terrestrial GHG data as part of credible and transparent national accounting systems. These opportunities are:

- Prioritizing R&D and tech transfer investments
- Providing tools and training
- Facilitating agreement on standardized methods
- Tailoring technical assistance
- Fostering south-south technical transfer
- Building on existing resources
- Designing inventory and monitoring strategies relevant to country circumstances
- Improving the quality of estimates

- Expanding the scope of monitoring

6. *Harmonization of reporting guidance across scales and sectors*

What are the primary research needs?

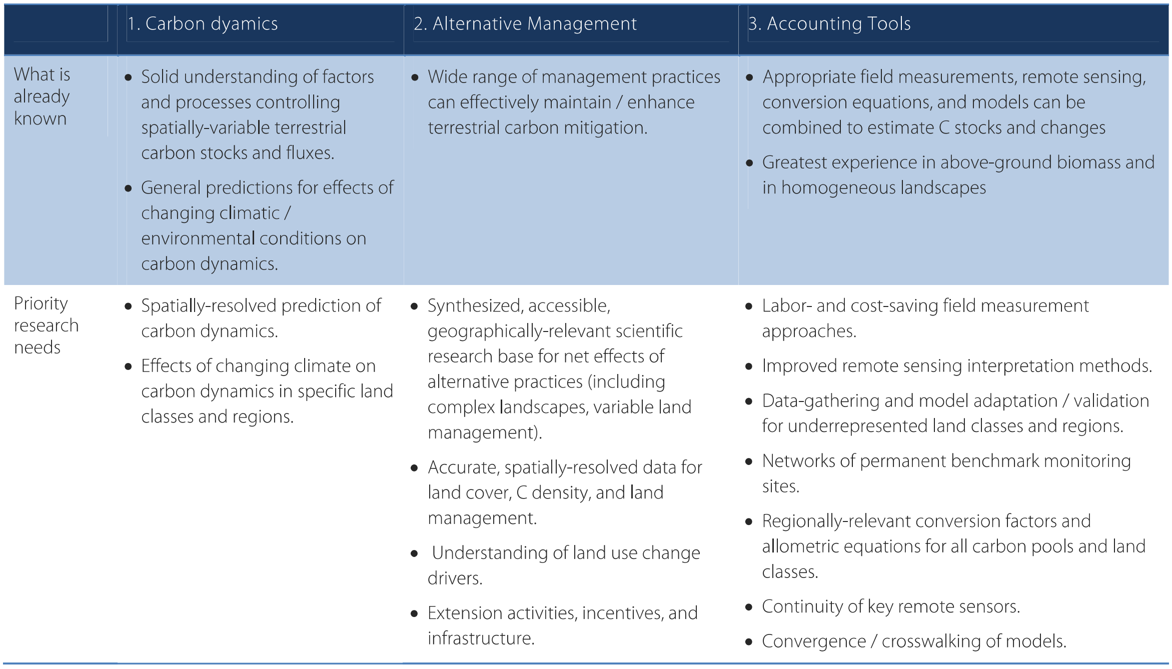
To make pragmatic and cost-effective investments related to terrestrial mitigation, stakeholders (e.g. countries, land managers, project developers) need greater clarify regarding expectations for receiving financial rewards under incentive schemes (e.g. regulated or voluntary offset markets). To increase investment in terrestrial mitigation activity, research must support project development, sub-national, national and regional initiatives. A key area for further work is harmonization of terminology, definitions, standards, methodologies and classification schemes. There may also be benefits to clarifying the relationship between monitoring change in land cover and interpretation of land use change so that reporting requirements are consistent and feasible. Progress in this area will however need to be balanced with accommodating country-specific conditions and pre-existing data systems.

What can be done to meet research needs?

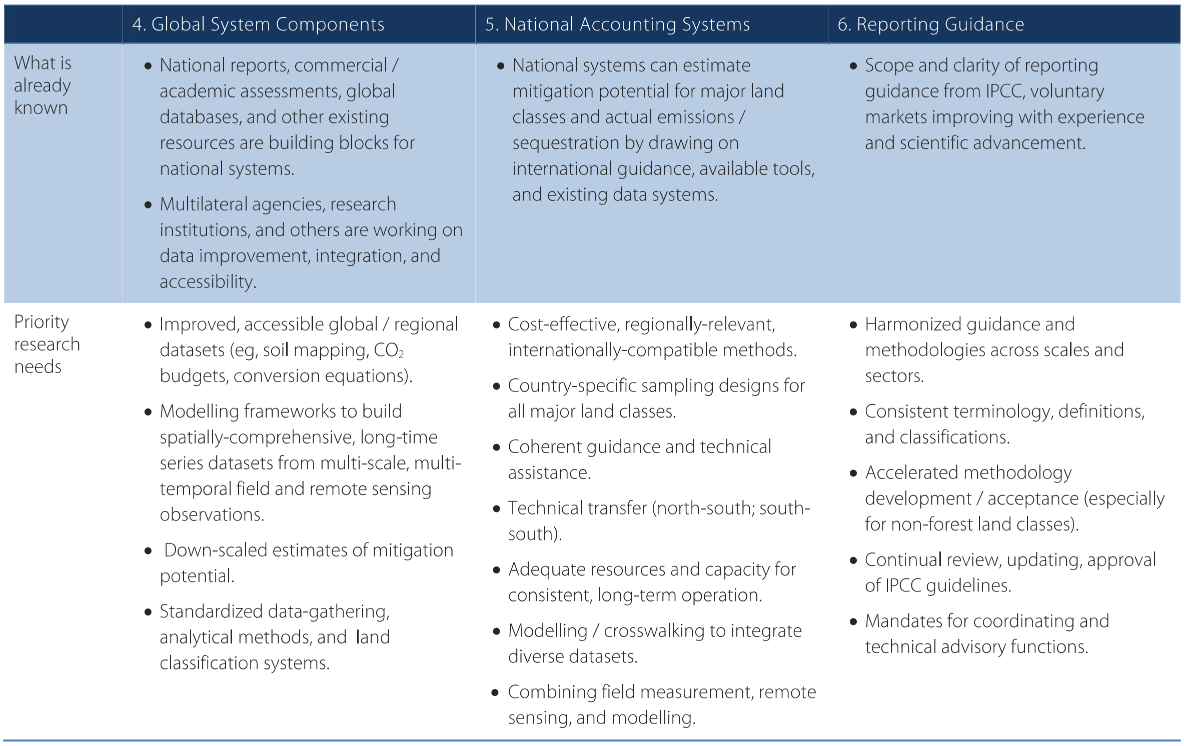
The international community can help to stimulate greater project-level activity and integrated terrestrial carbon accounting by harmonizing guidance for meeting expectations under financial incentive schemes. Specific opportunities include:

- Increasing consistency of terminology, definitions and classifications
- Updating of IPCC guidelines
- Accelerating acceptance of methodologies
- Increasing emphasis on agriculture and other land use
- Mandating coordinating and advisory functions

Table 5. What we know and priority research needs

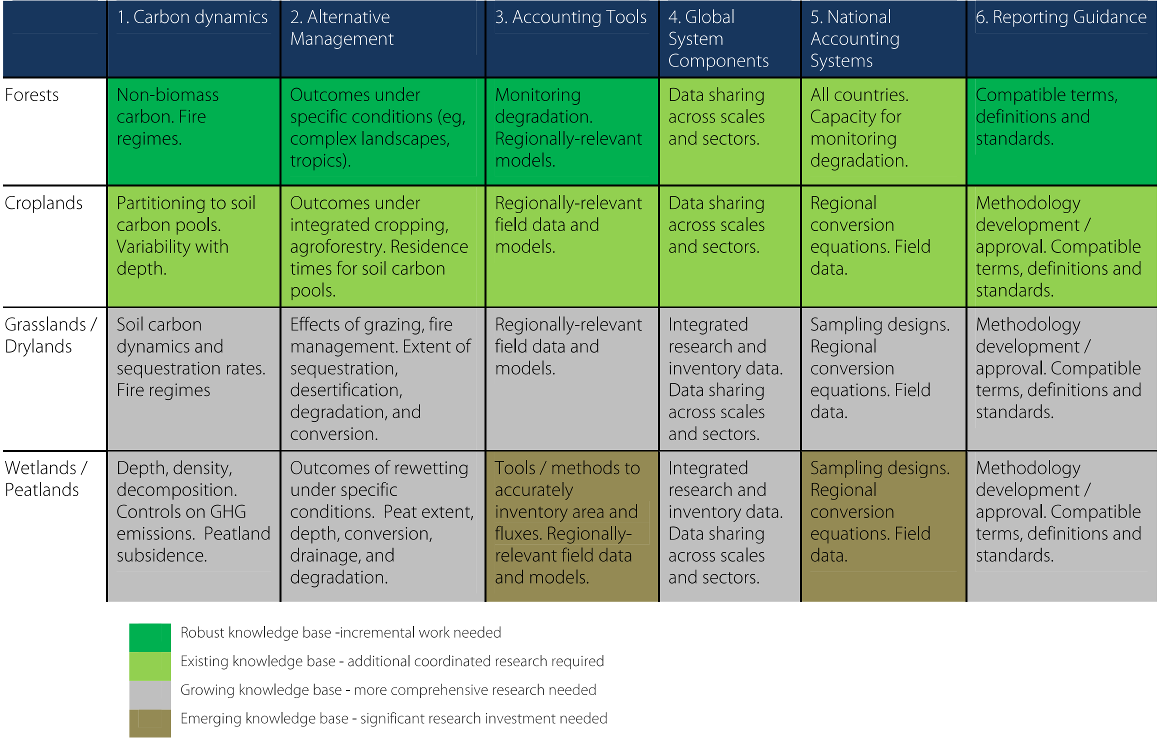


	1. Carbon dyamics	2. Alternative Management	3. Accounting Tools
What is already known	• Solid understanding of factors and processes controlling spatially-variable terrestrial carbon stocks and fluxes. • General predictions for effects of changing climatic / environmental conditions on carbon dynamics.	• Wide range of management practices can effectively maintain / enhance terrestrial carbon mitigation.	• Appropriate field measurements, remote sensing, conversion equations, and models can be combined to estimate C stocks and changes • Greatest experience in above-ground biomass and in homogeneous landscapes
Priority research needs	• Spatially-resolved prediction of carbon dynamics. • Effects of changing climate on carbon dynamics in specific land classes and regions.	• Synthesized, accessible, geographically-relevant scientific research base for net effects of alternative practices (including complex landscapes, variable land management). • Accurate, spatially-resolved data for land cover, C density, and land management. • Understanding of land use change drivers. • Extension activities, incentives, and infrastructure.	• Labor- and cost-saving field measurement approaches. • Improved remote sensing interpretation methods. • Data-gathering and model adaptation / validation for underrepresented land classes and regions. • Networks of permanent benchmark monitoring sites. • Regionally-relevant conversion factors and allometric equations for all carbon pools and land classes. • Continuity of key remote sensors. • Convergence / crosswalking of models.



	4. Global System Components	5. National Accounting Systems	6. Reporting Guidance
What is already known	• National reports, commercial / academic assessments, global databases, and other existing resources are building blocks for national systems. • Multilateral agencies, research institutions, and others are working on data improvement, integration, and accessibility.	• National systems can estimate mitigation potential for major land classes and actual emissions / sequestration by drawing on international guidance, available tools, and existing data systems.	• Scope and clarity of reporting guidance from IPCC, voluntary markets improving with experience and scientific advancement.
Priority research needs	• Improved, accessible global / regional datasets (eg, soil mapping, CO_2 budgets, conversion equations). • Modelling frameworks to build spatially-comprehensive, long-time series datasets from multi-scale, multi-temporal field and remote sensing observations. • Down-scaled estimates of mitigation potential. • Standardized data-gathering, analytical methods, and land classification systems.	• Cost-effective, regionally-relevant, internationally-compatible methods. • Country-specific sampling designs for all major land classes. • Coherent guidance and technical assistance. • Technical transfer (north-south; south-south). • Adequate resources and capacity for consistent, long-term operation. • Modelling / crosswalking to integrate diverse datasets. • Combining field measurement, remote sensing, and modelling.	• Harmonized guidance and methodologies across scales and sectors. • Consistent terminology, definitions, and classifications. • Accelerated methodology development / acceptance (especially for non-forest land classes). • Continual review, updating, approval of IPCC guidelines. • Mandates for coordinating and technical advisory functions.

Table 6. Research needs for major land classes



	1. Carbon dynamics	2. Alternative Management	3. Accounting Tools	4. Global System Components	5. National Accounting Systems	6. Reporting Guidance
Forests	Non-biomass carbon. Fire regimes.	Outcomes under specific conditions (eg, complex landscapes, tropics).	Monitoring degradation. Regionally-relevant models.	Data sharing across scales and sectors.	All countries. Capacity for monitoring degradation.	Compatible terms, definitions and standards.
Croplands	Partitioning to soil carbon pools. Variability with depth.	Outcomes under integrated cropping, agroforestry. Residence times for soil carbon pools.	Regionally-relevant field data and models.	Data sharing across scales and sectors.	Regional conversion equations. Field data.	Methodology development / approval. Compatible terms, definitions and standards.
Grasslands / Drylands	Soil carbon dynamics and sequestration rates. Fire regimes	Effects of grazing, fire management. Extent of sequestration, desertification, degradation, and conversion.	Regionally-relevant field data and models.	Integrated research and inventory data. Data sharing across scales and sectors.	Sampling designs. Regional conversion equations. Field data.	Methodology development / approval. Compatible terms, definitions and standards.
Wetlands / Peatlands	Depth, density, decomposition. Controls on GHG emissions. Peatland subsidence.	Outcomes of rewetting under specific conditions. Peat extent, depth, conversion, drainage, and degradation.	Tools / methods to accurately inventory area and fluxes. Regionally-relevant field data and models.	Integrated research and inventory data. Data sharing across scales and sectors.	Sampling designs. Regional conversion equations. Field data.	Methodology development / approval. Compatible terms, definitions and standards.

🟩 Robust knowledge base -incremental work needed

🟩 Existing knowledge base - additional coordinated research required

⬜ Growing knowledge base - more comprehensive research needed

🟫 Emerging knowledge base - significant research investment needed

Priorities: Time for action

Research and information synthesis for terrestrial mitigation techniques have not been equally distributed across GHGs, land use types, and regions of the world. Richer process-level understanding is needed across all land classes for historical, current, and potential GHG emissions and carbon sequestration as well as for drivers of land use conversion and degradation. There is a relative scarcity of information for drylands, wetlands and peatlands, non-biomass carbon pools and non-CO_2 GHGs.

There are significant differences in guidance for reporting emissions and sequestration across scales and sectors and streamlined processes are needed for approving consistent definitions, standards, and methodologies. There is considerable variety among countries in their ability to measure and monitor all types of terrestrial GHGs. While some have sophisticated measurement and monitoring capacity, in general, non-Annex I countries of the United Nations Framework Convention on Climate Change (UNFCCC) have limited data-gathering capacity and access to reliable existing datasets and conversion equations. Overall, there is inadequate consistency in data-gathering methods and resulting datasets across scales and sectors.

In seeking to advance the scientific and technical foundation for land-based mitigation, adequate resources, expanded capacity, and clear incentives and mandates are needed to capitalize on the following opportunities:

- Rich scientific knowledge and field experience, available measurement tools and databases, and existing reports and international guidance provide a solid foundation for current and future work.
- Development of cost-effective, easy to use tools and methods and spatially-resolved, accurate data-gathering is needed to expand focus to all land classes (including complex landscapes), regions, and carbon pools.
- Diverse local, regional and national circumstances can be accommodated by developing a regionally-relevant mix of management practices, measurement approaches, conversion equations, and models as well as adapting to climate change.
- Efforts to improve convergence and consistency can produce synthesized scientific knowledge, harmonized reporting guidelines and methodologies, compatible terminology, definitions, and classifications, and integrative modeling.
- Expanding and building regional and global networks can provide needed linkages across field research and technological advancements and facilitate access to tools, databases, technical support, infrastructure, and extension services.

To translate policy frameworks and financial incentives into improved land management and significant climate change mitigation, action and innovation will be needed by international agencies, national governments, land managers, financiers, and project implementers and auditors. Structured frameworks are needed to link together the array of idiosyncratic projects and programs housed in various research institutions, private companies, national and international agencies.

Continued and expanded leadership by research institutions and multilateral agencies can promote translational research that builds on existing knowledge and infrastructure, improves accuracy while developing experience, and informs policy and practice. An essential step will be estimating costs and capacity needs associated with research initiatives and generating the necessary financial and technical support. Linkages among developed and developing countries and across the public and private sectors will be critical to filling research gaps through coordinated, multi-lateral, multi-scale cooperation.

Some specific areas for consideration by the EU-JRC may include:

- Build on existing understanding of carbon dynamics and disturbance processes by implementing research (e.g. field studies) in understudied regions and land classes to ensure that estimated mitigation potentials are calibrated to a more accurate understanding of biophysical processes, geographic and temporal variability, and regional conditions for the full range of land classes and regions;

- Respond to the need for a more complete and integrated characterization of ecological landscapes, for example, by developing techniques for land classification in heterogeneous areas;
- Establish platforms for sharing research-scale findings (e.g. open source databases) to enlarge the pool of information available for meta-analysis of the controlling factors for GHG emission and carbon sequestration and multi-scale estimation of mitigation potential;
- Identify land management practices that maximize emissions reduction and sequestration in specific regions through study of the net effects of different practices in a more comprehensive set of geographic areas;
- Gather and analyze socio-economic data related to land use change drivers (e.g. population, food and fuel demand, infrastructure, commodity prices, governance);
- Develop new cost- and labor-saving measurement tools and methods relevant to terrestrial mitigation (e.g. tools for extracting information from field sampling, stratified remote sensing and field observations);
- Improve interpretation capacity for remote sensing (e.g. integrating data from different optical, laser, and radar remote sensing technologies, “crosswalking” remote sensing data streams gathered over multiple decades, linking biophysical variables to spectral reflectance);
- Adapt and verify existing models to broader set of regions and data streams;
- Integrate existing datasets (e.g. combining datasets from different national and regional programs and datasets developed over different time periods to produce the spatially comprehensive, long-time series data);
- Downscale terrestrial mitigation potential estimates (e.g. common geo-referencing across in situ observations, flux towers, air-and space-borne sensors);
- Facilitate agreement on standardized methods by coordinating frameworks and venues for agreeing standards for regionally-appropriate, internationally-compatible methods of measurement and analysis;
- Foster north-south and south-south technical transfer.

Research needs for monitoring, reporting and verifying soil carbon benefits in sustainable land management and greenhouse gas mitigation projects

N. H. Batjes[1]

Introduction

The human-induced increase in atmospheric greenhouse gas (GHG) concentrations poses a threat to the global environment and human well-being. Carbon dioxide, but also nitrous oxide and methane, are most notorious in this regard. Mitigating GHG emissions is a major challenge and needed to curtail climatic change (Bouwman 1990; Smith *et al.* 2008; Watson 2003; Lal 2004).

GHGs and their elements carbon, nitrogen, oxygen and hydrogen are part of global biogeochemical cycles. They occur in the atmosphere, oceans, vegetation and soils. Some two thirds of all terrestrial carbon is contained in the soil; vegetation accounts for the rest (Batjes 1996). Soils are important long-term reservoirs of organic carbon; inorganic (carbonate) carbon can be important in semi-arid and arid regions (Lal *et al.* 2000). The amount of carbon in soil, present in soil organic matter, is strongly influenced by changes in land use and management.

Agriculture, land use change and forestry account for 25-30% of global anthropogenic GHG emissions to the atmosphere (IPCC 2007; World Resources Institute 2010). The agricultural sector alone is responsible for about 12% of total GHG emissions (Smith *et al.* 2007a; UNFCCC 2008). At present, agricultural lands occupy some 40-50% of the Earth's land surface, with agriculture causing an estimated emission of 5.1-6.1 Gt CO_2-eq yr^{-1} in 2015 (Smith *et al.* 2007a). This points at a significant potential for mitigation through improved land management, particularly in Non-Annex I countries (Fig. 1).

According to the UNFCCC (2008), the global technical mitigation potential of agriculture, excluding fossil fuel offsets from biomass, by 2030 is estimated to be 5.5–6.0 Gt CO_2-eq per year. Some 89 per cent of this potential can be achieved by soil organic carbon (SOC) sequestration through cropland management, grazing land management, restoration of organic soils and degraded lands, bioenergy and water management (UNFCCC 2008).

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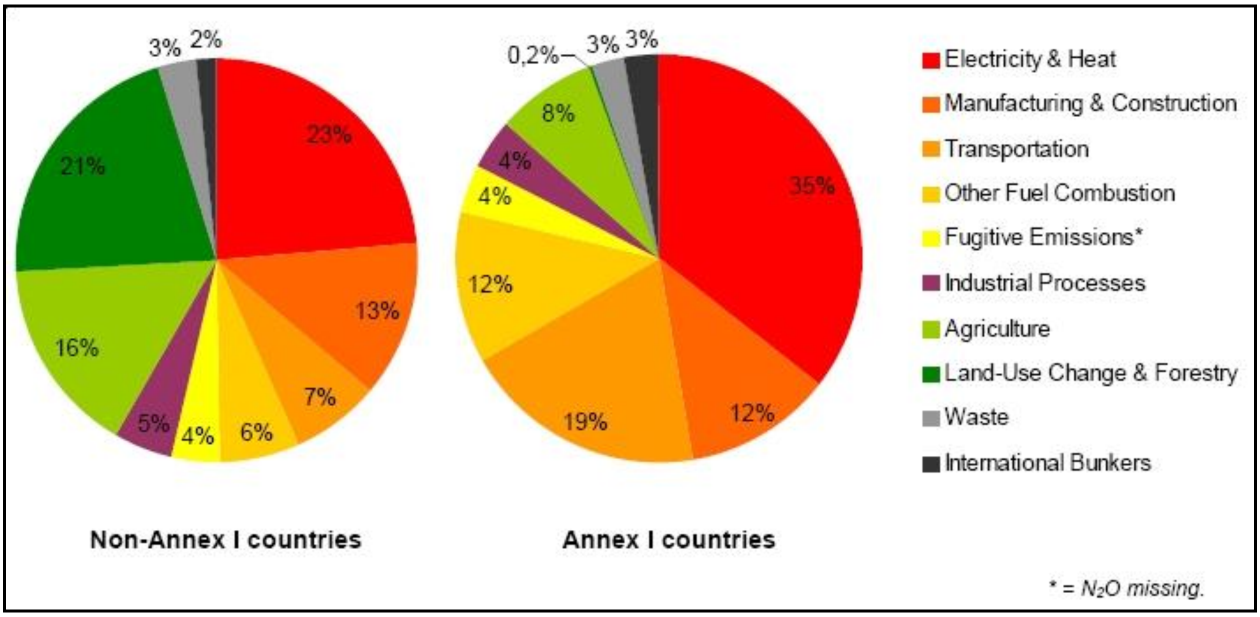

Figure 1. Emission sources in developing (non-Annex I) and developed (Annex I) countries (World Resources Institute 2010)

During the last decade, acceptance of the GHG mitigation potential of agricultural soils has increased. Various projects and other activities are being implemented worldwide. For example, a) in several countries, cropland activities have already been elected to officially account for SOC sequestration under the Kyoto Protocol (e.g., Canada, Denmark and Portugal); b) UN-REDD (Reducing Emissions from Deforestation and Forest Degradation in Developing Countries) and the on-going debate on REDD$^+$ have the potential to create new opportunities for agriculture and rural producers (e.g., food security, alleviating poverty, improving governance, conserving biodiversity and providing other environmental services); c) development of analytical solutions for field C (and GHG) measurement, monitoring and verification; d) development of tools for forecasting changes in C-balance respectively full carbon accounting, such as the GEF-CBP (Carbon Benefit Project) system (Milne *et al.* 2010a; Milne *et al.* 2010b) and FAO-EX-ACT tool (Bernoux *et al.* 2011); e) implementation of voluntary markets for trading C, such as the BioCarbon fund and the Chicago Climate Exchange (CCX). Nonetheless, there is a need for a robust technical and scientific information base to help translate policy frameworks and financial incentives into terrestrial carbon management.

The aim of this paper is to point at important development and research needs for monitoring, reporting and verifying (MRV) soil carbon benefits in sustainable land management (SLM) and GHG mitigation projects. As such, its scope is more illustrative than comprehensive.

Soil organic matter and sustainable land management

Organic carbon is stored in the soil as organic matter, comprising decomposed parts of above and below ground biomass. Soil fauna, roots, microbes and fungi interact with mineral and fresh organic matter to gradually create stable humus. Brussaard *et al.* (2007) and others have discussed the importance of soil biodiversity to sustain (agro)ecosystem functioning.

Many managed agro-ecosystems have lost 30-55% of their original SOC pool since land use conversion (e.g., Mann 1986; Sampson and Scholes 2000) on a volume basis; without soil mass correction, however, land use change effects may have been underestimated by some 30% according to Don *et al.* (2011). The carbon sink capacity of the world's agricultural and degraded soils is estimated at 50 to 66% of the historic carbon loss of 42 to 78 Gt of carbon (Lal 2004). Generally, depleted SOC stores can be improved through rehabilitation or judicious soil and water management (Fig. 2), but the possible gains are finite.

Under natural conditions, SOC levels remain at a certain equilibrium with the natural vegetation (Fig. 2; baseline is set at 100, see Y-axis). A change in land use and management, such as deforestation for timber or conversion to pasture or agricultural lands, breaks the natural cycle. Less organic material becomes available and the soil gets more exposed to the sun and the atmosphere. As a result, the amount of SOC will rapidly decrease to a lower equilibrium, generally within 5 to 10 years. Consequently, CO_2 and other GHGs will be released into the atmosphere, contributing to global warming. In addition, such SOC losses will be associated with losses in soil quality, for instance a reduced capacity for holding water and retaining nutrient cations, with adverse impacts on food security and biodiversity.

In agricultural systems, the amount of SOC can be increased only when organic matter inputs are greater than decomposition. This can be achieved by implementing recommended management practices (RMP) that include an adroit combination of: (a) conservation tillage in combination with planting of cover crops, green manure and hedgerows; (b) organic residue and fallow management; (c) water conservation and management; (d) soil fertility management, including use of chemical fertilizers, organic manures and liming; (e) introduction of agro-ecologically and physiologically adapted crop/plant species, including agroforestry; (f) adapting crop rotations, with avoidance of bare fallow; and (g) stabilization of slopes and terraces to reduce risk of erosion by water (e.g., Batjes 1999; Bruce *et al.* 1999; Paustian *et al.* 1998; Smith *et al.* 2007a). The selection of RMPs should be site specific.

The build-up of SOC proceeds slowly and generally takes decades of continuous best management practices. The new steady-state may be lower, similar and sometimes even greater (Fig. 2) than the antecedent SOC stocks. The latter has been the case, for example, with the Plaggen soils of Western Europe (Pape 1970) and Terra Preta dos Indios in the Amazon (Sombroek 1966) that have been historically enriched with organic materials and nutrients taken from surrounding locations.

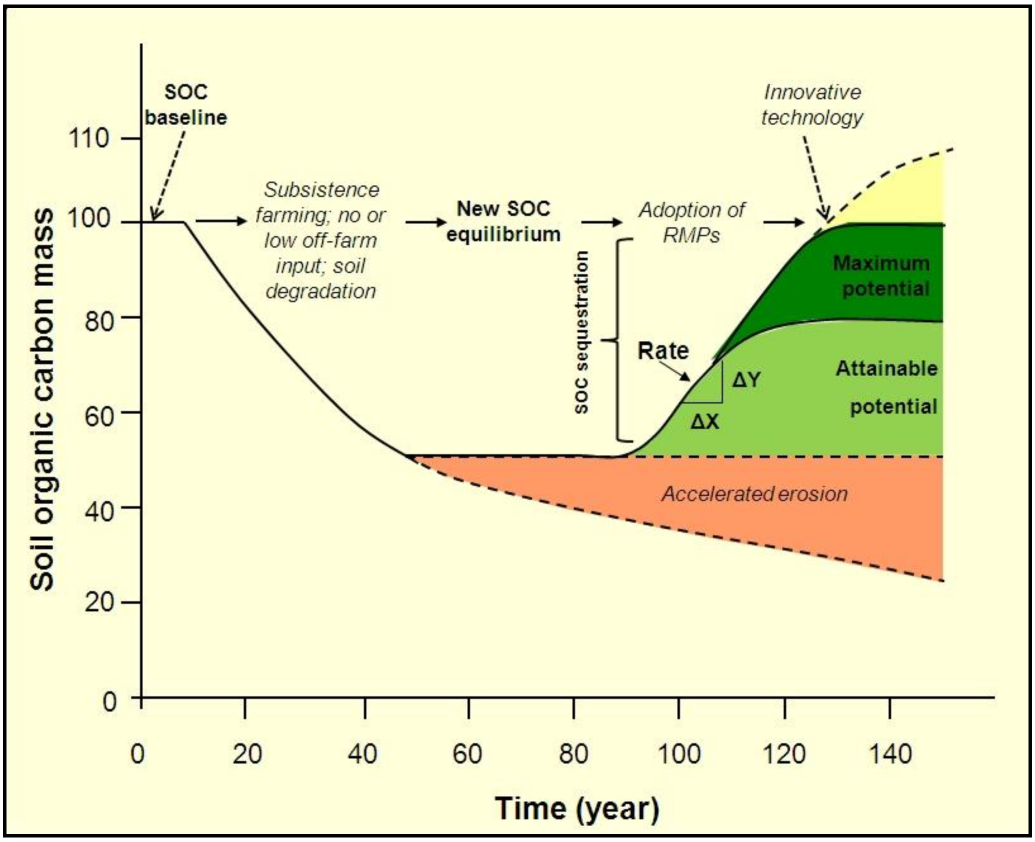

Figure 2. Adoption of recommended management practices (RMPs) can help restore SOC stocks and reduce GHG emissions (The baseline, on the Y-axis, is set at 100; modified after Lal, 2008)

Sustained adoption of RMPs is necessary to maintain and improve the productivity of soils, prevent soil degradation, increase biodiversity and thereby improve the performance and resilience of agro-ecosystems. Generally, options that both reduce GHG emissions and increase productivity are more likely to be adopted than those which only reduce emissions (Smith *et al.* 2007a).

Regional differences in SOC sequestration potential

The amount and vertical distribution of organic carbon in boreal, temperate and tropical soils vary greatly (Fig. 3, see Batjes and Sombroek 1997; Eswaran *et al.* 1995; Sombroek *et al.* 1993), due to regional differences in the intensity of the soil forming factors of climate, landscape position (relief), parent material, b**iological factors (p**lants, animals, micro-organisms, and mankind), and time (Jenny 1941). For example, for a given climate and vegetation type, soils formed on basic rocks will typically hold greater amounts of SOC than those developed over acid rocks. Global, area-weighted averages for SOC content range from about 4 kg C m^{-2} to 100 cm depth for soils of arid regions, where plant growth is limited, to about 24 kg C m^{-2} for soils from boreal regions (Batjes 1999).

For a given climate/soil stratum, the possible magnitude and rate of SOC sequestration will depend on: a) the baseline or reference level; b) antecedent SOC pool (land use history), c) soil properties, such as depth of soil, clay content and mineralogy, drainage/aeration conditions, and soil nutrient status; d) the type of RMPs adopted; and, e) socio-economic conditions/incentives.

Figure 3. The amount and vertical distribution of organic carbon varies greatly between and within boreal, temperate and tropical soils (Source: ISRIC).

High C-costs may be incurred in areas where natural processes do not effectively favour C sequestration, such as in arid regions (e.g., through fuel use for irrigation). As such, there is a need to identify regions and land management practices with a high potential for GHG emission reduction and SOC sequestration across the full range of world climate/soil/land use types. Although there are many different measures to protect/improve soils and SOM content, often their *net* GHG effects are not well documented and evaluated. Indicative rates of biophysically feasible SOC sequestration rates for defined land use activities and climatic zones, following adoption of specific RMPs, have been discussed in many papers. Overall, world croplands may sequester some 0.1-1.5 Mg C ha^{-1} yr^{-1} depending on climate, soil type, management practices and socio-economic conditions/incentives (e.g., Batjes 1999; Bruce *et al.* 1999; Sampson and Scholes 2000; Smith *et al.* 2007a).

Every measure that increases SOC content is likely to have beneficial impacts on soil properties and functions. In this context, it is especially important to evaluate the socio-economic feasibility of alternative management options, and their possible impact on human well-being through effects on e.g. food security. As observed by Janzen (2006), it is the biological turnover of organic C that is important for function, not just the amount accumulated in stable C-pools; for a critical examination see Powlson *et al.* (2011).

Measuring, monitoring and modelling SOC changes

Knowledge of how different land management strategies will affect agro-ecosystem carbon stocks and GHG changes, land degradation and sustainability remains far from complete (e.g., IPCC 2006; Kogel-Knabner *et al.* 2005; Powlson *et al.* 2011). The above reveals the need for a better understanding of the role of soils and the vegetation that grows on it as natural regulators of GHG emissions and climate change. Estimating SOC stock and GHG emission changes on any scale will require access to a wide range of databases: climate, terrain, soils and land use/vegetation, as well as the main socio-economic drivers. Managing, sustaining and utilising such databases, especially at the continental and global level, will require enduring efforts; the same applies for model development and testing.

Relationships between environmental/management factors and SOC dynamics can be established using experimental field-trials, chronosequence studies and monitoring networks. Soil monitoring networks (SMN), for example, can provide information on: direct changes of SOC stocks through repeated measurements at a given site; data to parameterise and test biophysical models at plot scale; a set of point observations that represents the variation in climate/soil/land use management at national scale, allowing for up scaling. As shown by a recent review (van Wesemael *et al.* 2011), many SMNs are in the planning or early stages. Within such networks, monitoring sites may be organised according to different sampling schemes, for example regular grid, stratified approach or randomized (e.g., ISO 2002; Ravindranath and Ostwald 2008; UNFCC 2009). Further, there are numerous protocols for field sampling and measuring SOC (e.g., GOFC-GOLD 2009; ISO 2002; McKenzie *et al.* 2002; Pearson *et al.* 2005; Stolbovoy *et al.* 2007), thereby providing a possible source of confusion also since C-projects may have different objectives.

Basically, there are two types of C-projects: climate change mitigation, with strict C and GHG reporting needs (e.g., CDM and REDD$^+$) and Sustainable Land Management projects the focus of which is on food security, farmer livelihood, resilience and biodiversity. Increasingly, SLM projects also need to assess broad impact of interventions on SOC and GHG fluxes, as is the case, for example, within the Green Water Credits (GWC) project (Geertsma *et al.* 2010). Overall, projects should be encouraged to use the most accurate methods possible, given the resources available and project objectives (Milne *et al.* 2010a; Milne *et al.* 2010b).

Because SOC levels are particularly sensitive to changes in land use practices, these can be regulated through land use policy interventions (e.g., Izac 1997; Koning *et al.* 2001; Smith *et al.* 2007b). Carbon-fixing projects that claim *environmental benefits* have paid most attention to carbon in vegetation rather than in the soil, primarily because of the relative ease of measurement. Compared with biomass carbon, SOC must be monitored over longer periods because the changes are small relative to the very large stocks present in the soil as well as the inherent variability; this requires sensitive measurement techniques. Methodological efforts are needed to ensure that SOC stock changes can be detected consistently (known accuracy, within defined permissible error) across complex landscapes.

Studies of SOC dynamics have been hampered by the difficulty of sampling and observing processes beneath the earth's surface. Standard methods of soil analysis are often too expensive for continuous monitoring, in view of the large number of samples/analyses involved. Various promising techniques are under development (e.g., Gehl and Rice 2007; Viscarra *et al.* 2010). Inelastic Neutron Scattering (INS, e.g., Wielopolski *et al.* 2011), Infra-Red Reflectance Spectroscopy (Vis-NIR and Mid-IR, e.g., Ladoni *et al.* 2009; Reeves *et al.* 2002; Terhoeven-Urselmans *et al.* 2010) and Laser-Induced Breakdown Spectroscopy (LIBS, e.g., Ebinger *et al.* 2006; Martin *et al.* 2003), for example, can provide rapid, accurate and more cost-effective measurements, once calibrated. Further, Gamma-spectroscopy appears promising for rapid measurement of bulk density (e.g., Mostajaboddavati *et al.* 2006), required to compute SOC stocks.

Remote sensing (RS) provides direct observations of land surface features/processes, thereby increasing the accuracy of SOC change predictions. In the future, new RS techniques may permit routine monitoring of changes in selected chemical and physical properties of soil, though only to a limited depth. Operational RS assessment of SOC stocks, however, is not yet possible according to the Terrestrial Carbon Group (2010). Alternatively, the accuracy and precision of such methods is rapidly improving as more experience is gained (Mulder *et al.* 2011).

Carbon offset markets

It remains difficult to assess the environmental benefits associated with SLM projects because these should be determined according to standardised criteria and procedures. Many different methodologies have been developed/tested in different countries; a co-ordinated effort is needed to ensure that these methods are comparable/cross-referenced. Feasible accounting respectively modelling tools are needed for all lands and carbon pools, and these should consider all GHGs. The GEF co-funded Carbon Benefits Project (CBP), for example, is developing a standardized, cost-effective methodology that is comprehensible, standardized, robust and applicable to all GEF-SLM projects to: (1) permit the GEF (and others) to monitor the net C impacts of its investments in AFOLU projects, and (2) provide an enhanced capacity of SLM-projects to engage with the emerging carbon-offset markets (see CBP-CSU 2009-2012; Milne *et al.* 2010a). Overall, the “attractiveness” of a project will depend on the buyer’s objectives, and requirements will be different for a “compliance” (e.g., CDM) or “voluntary” (e.g., CCX) buyer (Kollmuss *et al.* 2008) .

Concluding remarks

Many challenges remain to making agriculture part of the mitigation agenda, also in view of the many trade-offs between forestry approaches to mitigation and agricultural approaches (Campbell 2009).

Based on the preceding overview, several priorities for further research on monitoring, reporting and verification systems for carbon in soils and vegetation may be identified:

- Increase process-level understanding of carbon dynamics, subject to changes in land use management and climate
- Development of cost-effective techniques to measure and monitor all C pools (and GHGs) to reduce the need for conventional laboratory analyses; implementation of QA/QC procedures
- Creation of, and long-term support, for national scale MRV systems; capacity building
- Development and validation of scaling procedures (accounting and modelling) at field, landscape and broader scales, ultimately for all terrestrial C pools and GHG fluxes; also, quantified uncertainty.
- Development of a tier-based, global information system with main socio-economic and biophysical driving variables, at relevant scales, to support modelling; ideally, open-access through web-services.
- Streamlined processes for harmonizing definitions, standards and methodologies.

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RESEARCH NEEDS FOR AGRICULTURE AND RURAL DEVELOPMENT POLICIES

Current JRC activities in carbon in soils

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The SOIL Action of the JRC is aiming at the development of policy relevant soil data and information systems. This activity has been running at JRC for more than 20 years and has developed the main reference data on European soils at various levels of detail.

This Action, which belongs to the Land Management and Natural Hazards Unit of the Institute for Environment and Sustainability, will run for the whole period 2007-2014 of the EU's Seventh Research Framework Programme (FP7). The specific objectives of the SOIL Action are the followings:

- The establishment of the European Soil Data Centre (ESDAC) as a single focal point for all soil data and information in Europe.

- The development of procedures and methods for data collection, quality assessment and control, data management and storage, data distribution to European Commission and external users, fully complying with INSPIRE (Infrastructure for Spatial Information in Europe) Directive principles.

- Research on and the development of advanced modelling techniques, indicators and scenario analyses in relation to the major threats to soil (erosion, decline of organic matter, compaction, salinisation, landslides, sealing, contamination and decline in biodiversity), as identified in the Thematic Strategy for Soil Protection .

- The support to other Commission's services with soil information and scientific as well as technical assistance in negotiating the proposal for a Soil Framework Directive (COM (2006) 232) (as part of the Thematic Strategy for Soil Protection) through the EU Institutions and its subsequent implementation at Community and Member State level.

- The extension of the coverage of the European Soil Information System (EUSIS) towards a fully operational Global Soil Information System (GLOSIS), providing relevant soil information for

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the implementation of multilateral environmental agreements, like UNFCCC, CBD and UNCCD, and contributing to the ground segment of the Global Monitoring for Environment and Security (GMES). The main information layer developed by SOIL Action is the 1:1,000,000 scale Soil Geographical Database of Europe (SGDBE) that forms the backbone of the European Soil Information System (EUSIS).

ESDAC is the thematic centre for soil related data in Europe and has been established according to a decision taken at the end of 2005 by the European Commission's DG ENV, DG JRC, ESTAT and the European Environment Agency (EEA) to establish ten environmental data centres in Europe. As a new development within FP7, the SOIL Action has established ESDAC as an INSPIRE compliant fully nested system on soil data and information operated by a network of national and regional data centres. The primary responsibility of ESDAC is to organize the availability and quality of the soil data required for policy making. Data come from projects run inside the EU institutions but also from collaborative projects between JRC and several research partners, such as FAO, ISRIC and ESBN (European Soil Bureau Network).

The SOIL Action manages the European Soil Portal (*http://eusoils.jrc.ec.europa.eu/*) which contributes to a thematic data infrastructure for soils in Europe and acts as a web-platform for ESDAC. The portal also connects to all the SOIL Action activities. It presents data and information regarding soils at European level and, when possible, provides links to national or global datasets. The above-mentioned soil dataset refer to all digital resources grouped in data, maps and application/services. The followings are available on the European Soil Portal:

- Data: an inventory of and access to the soil data that the JRC is currently holding
- Maps: a library of scanned maps and a collection of prepared maps derived from the existing soil databases at JRC.
- Applications/services: offers the user the possibility to interact on-line with many of the data held in soil related databases at JRC.

The European Soil Portal also serves as a vehicle to promote the activities of the ESBN. The latter was created in 1996 as a network of national soil science institutions and is operated at JRC by staff members of the SOIL Action. Its main tasks are to collect, harmonise, organise and distribute soil information for Europe.

Soil organic carbon in Europe

In the framework of the Thematic Strategy for Soil Protection, the decline of soil organic carbon (SOC) is identified as one of the main soil threats together with erosion, decline in organic matter, local and diffuse contamination, sealing, compaction, loss of biodiversity, salinization, floods and landslides.

SOC is the major component of soil organic matter and is extremely important in all soil processes. Organic material in the soil is essentially derived from residual plant and animal material, synthesized by microbes and decomposed under the influence of temperature, moisture and ambient soil conditions. The annual rate of loss of organic matter can vary greatly, depending on cultivation practices, the type of plant/crop cover, drainage status of the soil and weather conditions. There are two groups of factors that influence inherent organic matter content: natural factors (climate, soil parent material, land cover and/or vegetation and topography) and human-induced factors (land use, management and degradation).

At the European level, there is a serious lack of geo-referenced, measured and harmonised data on soil organic carbon available from systematic sampling programmes. At the present time, the most homogeneous and complete data on the organic carbon/matter content of European soils remain those that can be extracted and/or derived from the European Soil Database (ESDB) (*http://eusoils.jrc.ec.europa.eu/ESDB_Archive/ESDBv2/fr_intro.htm*), in combination with associated databases on land cover, climate and topography. The latter database is the only comprehensive source of data on the soils of Europe harmonised according to a standard international classification (FAO). The European Soil Portal makes available the map of Topsoil Organic Carbon Content (%) (OCTOP) and the map of Organic Carbon per country in petagrams (Pg) of soils in Europe. The data are in ESRI GRID format and are available as an ASCII raster file or in native ESRI GRID format. In addition, an interactive application allows the user to navigate in the organic carbon data with OCTOP Map Server and print his own customized map.

JRC activities related to carbon in soils

The SOIL Action is involved in several issues related to carbon in soils namely the assessment of organic carbon content and stocks; the collection and harmonization of EU Member States data; the monitoring of soil organic matter/carbon decline and sequestration potential; the establishment of a proposal for a common sampling methodology aiming at soil carbon estimates; the refinement of pedotransfer rules and functions; the mapping land cover/land use changes, the assessment of the effect of agricultural management practices on SOC, a research study on the potentiality of biochar application, etc.

Of particular importance within the SOIL Action is the development of new advanced digital soil mapping techniques based on geo-statistical analysis and new measurement techniques. Two on-going research projects of digital soil mapping (DIGISOIL and I-SOIL) have developed already promising results. The final aim of this research will be to develop tools that will allow for the rapid, cost effective and precise measurement of SOC content on a regular basis in Europe allowing for easy verification and reporting on SOC changes.

The SOIL Action is also performing a number of soil surveys campaigns aiming at the collection of updated SOC data for Europe. For forest soils these data are already completed and are part of the data collected within the BioSoil Demonstration project that was carried out in the course of the Forest Focus1 Regulation. As for all land uses a new regular monitoring for SOC has been performed within the Land Use/Land Cover Area frame statistical Survey (LUCAS) of Eurostat.

BioSoil: Demonstration project for monitoring organic carbon storage in European forest soils

In the course of Forest Focus2 the BioSoil Demonstration Project was carried out with the aim of investigating how a large-scale European study can provide harmonised soil and biodiversity data and contribute to research and forest related policies. One of the main objectives of the project was the evaluation of organic carbon (OC) stored in soils under forest in Europe.

The BioSoil soil survey was performed in 23 Member States. For estimating forest soil properties at regional and European scale the sample sites of the large-scale survey were arranged systematically on a 16 x 16 km grid. The BioSoil sample sites were intended to coincide with the locations of a forest soil condition project of 1996. This arrangement of sites was intended to allow estimating changes in SOC over an approximately 10 year period.

The distribution of the average OC content in the organic layer and the mineral topsoil (0 – 20 cm) by major region is presented in Fig. 1.

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2 Regulation (EC) No. 2152/2003

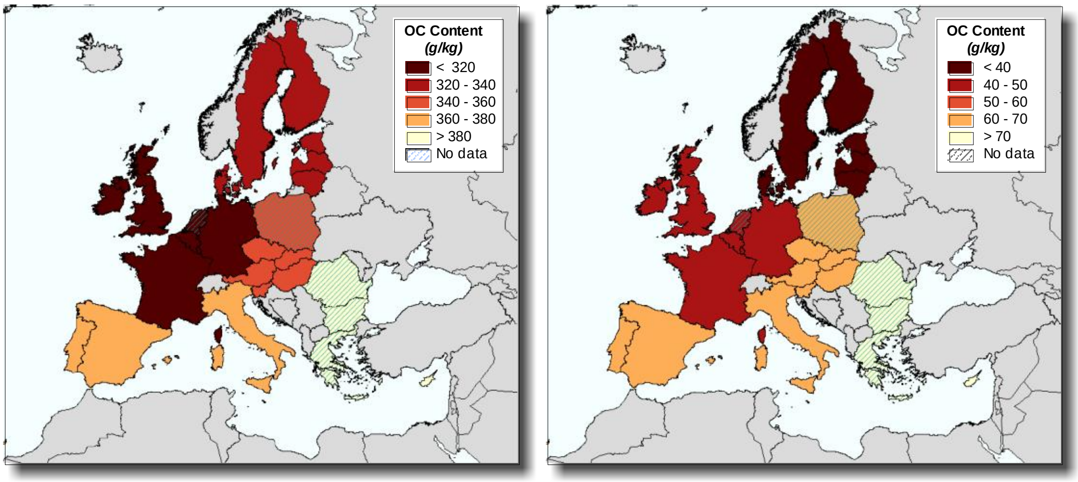


Figure 2. Mean Organic Carbon Content (g/kg) in Organic Layers and in Mineral Layers (0-20cm) of forest soils.

The maps show a distinctly diverse regional distribution of OC content in the organic layer and in mineral topsoil. The highest OC content in the organic layer were reported for sites in the North West European region (384.8 $g\ kg^{-1}$) and lower contents (300.5 $g\ kg^{-1}$) in the southern regions of the Mediterranean basin. For the upper 20 cm mineral soil the mean OC content for a region is highest under forests in the Nordic Baltic region (77.1 $g\ kg^{-1}$), followed by soils of the North West region (62.1 $g\ kg^{-1}$). With 18.6 $g\ kg^{-1}$ the OC contents is lowest in forest soils in South Eastern Europe. The average OC content for the survey area is 366.5 $g\ kg^{-1}$ for the organic layer and 61.7 $g\ kg^{-1}$ for the upper soil substrate. For all estimates the figures for the South Eastern region are highly biased by the values reported for Cyprus, since no data were reported for sites of the large-scale monitoring survey by Bulgaria, Greece and Romania.

The mean OC density of all sites of the BioSoil survey is 70.1 $t\ ha^{-1}$ (± 1.8 $t\ ha^{-1}$, 95% confidence level). Under the assumption that the mean OC density for areas without data can be estimated from the regional mean i.e. for The Netherlands from North West Europe and for Poland, Austria and Hungary from Central Europe, the OC stock in soils to a depth of 20cm is estimated at 9.6 Gt. No suitable survey data from the demonstration project are available to estimate OC stocks for South East Europe.

Compared to the first forest soil condition survey, the BioSoil Demonstration Project found an increase in organic carbon in the organic and upper 20 cm soil layer for the majority of revisited sites. However, changes in sample analysis methods between the two surveys hinder quantifying this trend in the data unequivocally. The changes in OC quantity in the combined organic layer and soil material to a depth of 20 cm are presented in Fig. 2.

Assessing changes in OC density from the FSCC/ICP Forest survey to BioSoil is limited to plots common to both surveys and subject to differences in the field sampling and soil analysis methods. A clear trend of an increase in OC is only found on plots in Portugal and on the few plots in Sweden. Only on plots in the Slovak Republic was there a general trend of a decrease in OC between surveys. On plots in other participating countries, both increases and decreases in OC density were found.

A significant role in producing the differences in OC quantity obtained from the two datasets are attributed to methodological divergences between countries and between the surveys, such as the approach to separating the organic layer from the mineral soil material and the analysis method used to determine the OC content in organic layers in the previous survey.

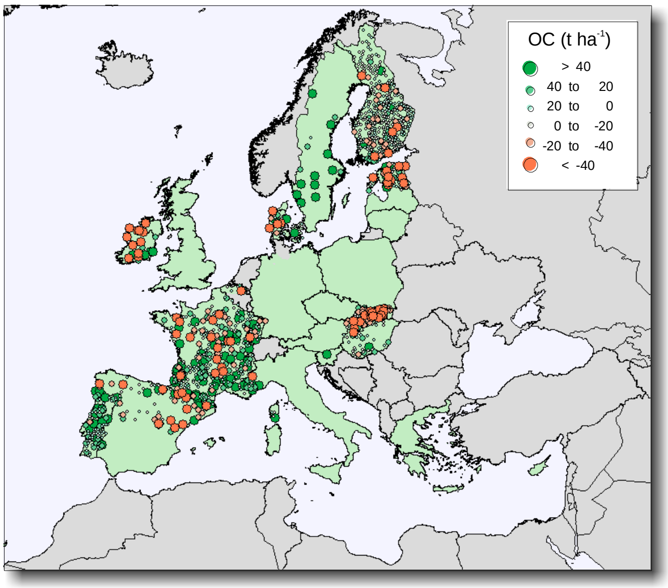


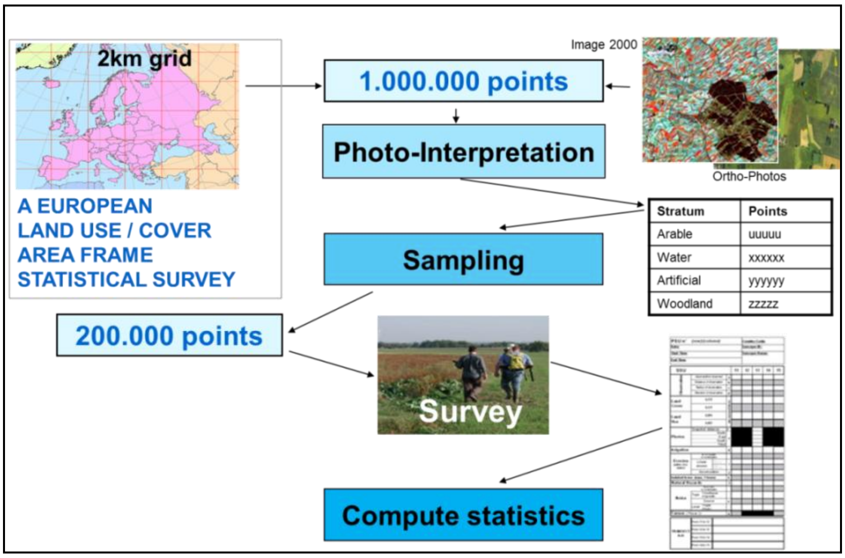
Figure 3. Change in Organic Carbon Density in Combined Organic and Mineral Topsoil(0-20 cm) Layer from FSCC- ICP Forests to BioSoil.

LUCAS (Land Use/Land Cover Area frame statistical Survey)

LUCAS project is directly coordinated by the SOIL Action to support the Thematic Strategy for Soil Protection. Initially, the general LUCAS aimed to monitor changes in management and coverage of the European territory and was based on the visual assessment of parameters relevant for agricultural policy. The sampling, based on a regular grid across Europe and defined as the intersection points of a 2 x 2 km grid covering the territory of the EU, resulted in around 1 million geo-referenced points. Each point was classified into 7 land cover classes using ortho-photos or satellite images. From the stratified master sample, a sub-sample of 200,000 points was extracted to be classified by field visit (2006) according to the full land nomenclature. The 2006 survey was carried out in 11 Member States to test the methodology at EU level with a restricted budget. The focus of the survey was agricultural land with a sampling rate of 50% for arable land and permanent crops, 40% for grassland and 10% for non-agricultural land. Fig. 3 shows the sampling scheme of the general LUCAS survey.

In the context of the 2009 LUCAS soil survey, a sub-sample of approximately 22,000 points was selected and topsoil samples (0-30 cm) were collected mainly from agricultural land. The samples, weighing around 11 tons in total, are stored in the European Soil Archive Facility, at JRC (Ispra site). The LUCAS 2009 topsoil survey aimed to produce the first coherent sampling and harmonized physicochemical analysis of soils from 25 EU Member States (EU-27 except Bulgaria and Romania). Soil samples were analysed for basic soil properties, including particle size distribution, pH, organic carbon, carbonates, NPK, CEC and multispectral properties. The LUCAS topsoil dataset represent the most comprehensive topsoil information base at EU level. Data on land management practices are available from the general LUCAS, allowing the analysis of the effect of land management on various soil properties, including SOC.

LUCAS project provides new data for the estimation of topsoil carbon distribution in Europe as well as for the assessment of soil carbon sequestration potential. Moreover preliminary studies have been performed on the dataset, taking climatic zones, regions and management practices into consideration. Results highlight important linkages among these factors and help understanding and quantifying the potential of European croplands with regards to carbon sequestration and other major soil functions. Another ongoing study aims at correlating LUCAS 2009 soil multispectral data with SOC measurements. A possible correlation would allow operational soil mapping avoiding physicochemical lab analysis.



Stratum	Points
Arable	uuuuu
Water	xxxxxx
Artificial	yyyyy
Woodland	zzzzz

Figure 4. LUCAS general survey sampling scheme.

EIONET

The European environment information and observation network (EIONET) aims to provide timely and quality-assured data, information and expertise for assessing the state of the environment in Europe and the pressures acting upon it. In the context of the development of ESDAC, it was jointly decided by the European Environment Agency and JRC that all soil data management activities carried out by EEA in collaboration with EIONET will be transferred to the JRC. The latter, through EIONET, is organising a data collection exercise among member countries with the objective of creating a European wide dataset for SOC and soil erosion according to a grid based approach. Fig. 4 presents the results obtained from the 2010 SOC data collection exercise.

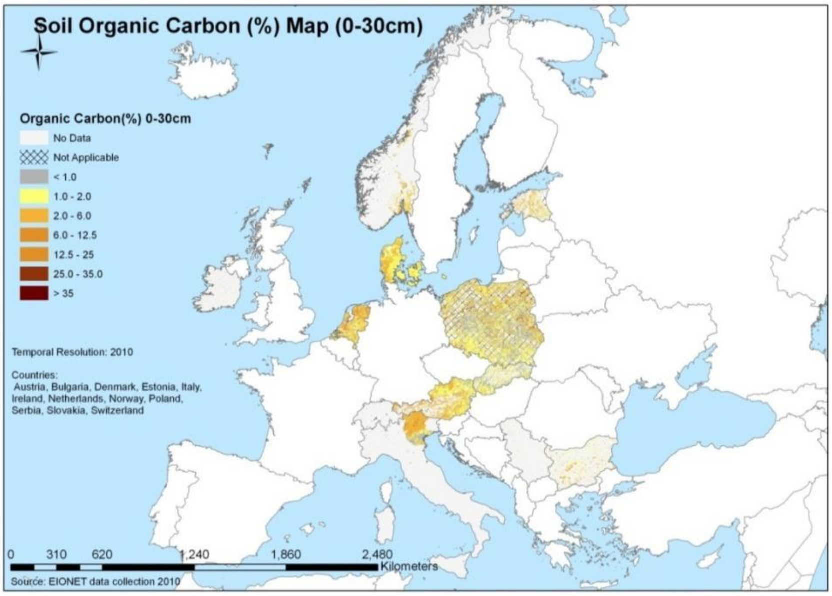


Figure 5. Map of the topsoil OC content (%) in EU countries having responded to the EIONET 2010 data collection exercise.

Estimation of changes in SOC as an indicator in land use change modelling

The estimated changes in SOC stocks from modelled changes in land use is one of the indicators used to evaluate the impact of various scenarios of agricultural policies in support to DG AGRI and DG ENV. The change in land use is given by comparing the status of the base year (2010) with the year of the final model run (2020).

Changes in SOC stocks are estimated following the Tier 1 approach of the Intergovernmental Panel on Climate Change (IPCC). The method is based on using default values for organic carbon (OC) in the topsoil (0 - 30cm), which are adjusted by climatic region. These basic SOC values are then moderated by the land use, management practices and fertilizer input. Changes in any of the defining parameters lead to subsequent changes in the SOC. In the case of this simulation the climate parameter was kept constant and only the land use parameter was modified according to the output from the land use model. The changes in carbon stocks are estimated for mineral soils and take management practices into account for cropland and grazing areas. To better support identifying policy options data from the 100m resolution spatial layers are aggregated to NUTS and processed by country.

Fig. 5 shows for the Czech Republic the change in SOC in Mt C at NUTS Level 2 from the base year to 2020 for the scenario “Status Quo”.
The changes in SOC due to changes in land use result in estimated reduction of 0.71 Mt C for the country. These changes occur with regional differences where some regions also show increases in SOC from the base to the scenario condition.

The effectiveness of the measures under the integration scenario was evaluated by comparing the difference in the changes between the status quo and the integration scenarios. The outcome is shown in Fig. 6.

The overall trend of the Integration scenario over the Status Quo scenario is a relatively higher amount of SOC for all NUTS Level 2 regions. The difference in SOC at country level is a saving of 0.69 Mt C. This translates to a saving of emissions of 2.53 Mt CO_2 of the Integration scenario over the Status Quo.

The main land cover changes contributing to the difference in estimates changes in SOC were assessed by studying the transmutations between land cover types. For the IPCC classes the differences between the conversion from the base situation to the Status Quo and to the Integration scenarios were compared as area changes.

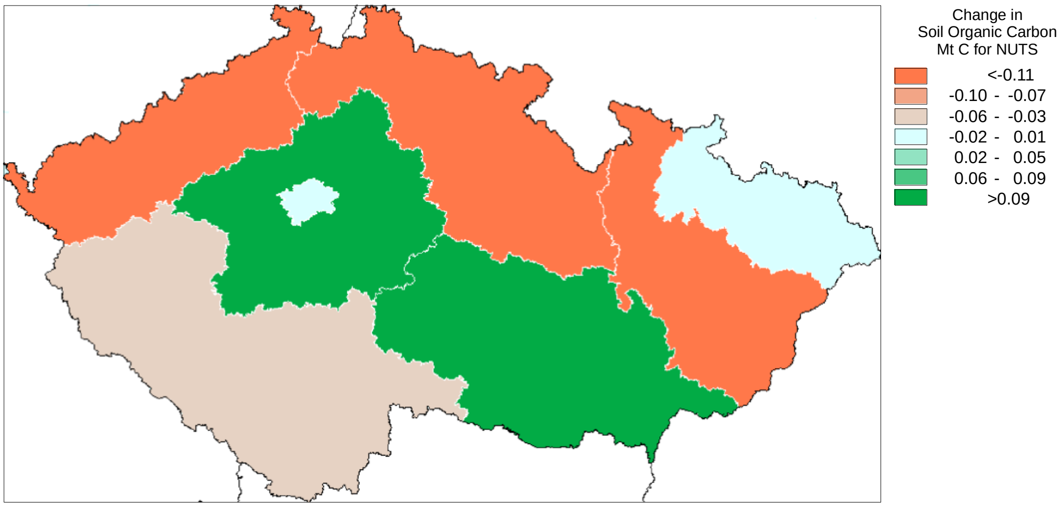


Figure 6. Estimated Change in SOC from Base to Status Quo Scenario over 10 Years (Czech Republic).

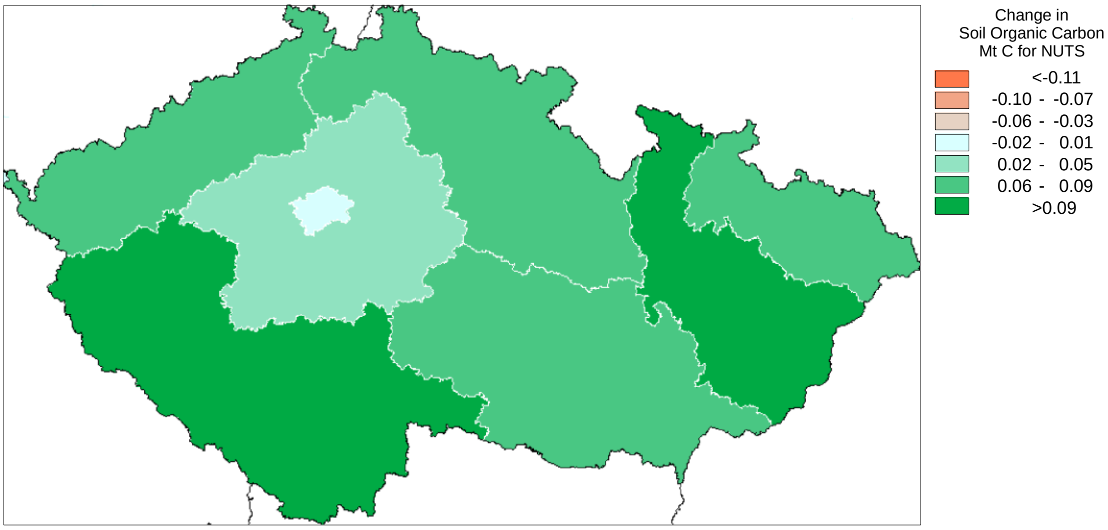


Figure 7. Estimated Change in SOC of Integration Scenario over Status Quo Scenario over 10 Years (Czech Republic).

Biochar

Biochar application to soils is being considered as a means to sequester carbon while concurrently improving soil functions. Biochar is defined as “charcoal (biomass that has been pyrolysed in a zero or low oxygen environment) for which, owing to its inherent properties, scientific consensus exists that application to soil at a specific site is expected to sustainably sequester carbon and concurrently improve soil functions (under current and future management), while avoiding short- and long-term detrimental effects to the wider environment as well as human and animal health." Biochar as a material is defined as "charcoal for application to soils". It should be noted that the term biochar is generally associated with other pyrolysis products such as biofuels (syngas and bio-oil). A report has been published by the SOIL Action and the main focus was to provide a critical scientific review of the current state of knowledge regarding the effects of biochar application on soil properties, processes and functions. Wider issues, including atmospheric emissions and occupational health and safety associated to biochar production and handling, are put into context. The review has provided a sound scientific basis for policy development, for identification of gaps in current knowledge, and for recommendations how biochar research should evolve to become more comprehensive in studied environmental variables (also for longer time series), and more harmonized in the experimental methodologies, methods and scientific reporting.

The JRC performed the first ever quantitative meta-analysis of the effect of biochar on crop productivity, using all available results of experiments worldwide, which showed a grand mean positive effect of ca. 10% increase in crop productivity. However, a limited number of combinations of environmental and management conditions have been studied, and a strategic research effort is required to allow elucidation of mechanisms. Ultimately, in those conditions where biochar application is beneficial to agriculture and environment, it should be considered as part of a soil conservation package aimed at increasing the resilience of the agro-environmental system combined with the sequestration of carbon. The key is to identify the agri-soil management strategy at a specific site that is best suited for a biochar with specific properties. Other carbon sequestration and conservation methods, such as no-till, mulching, cover crops, complex crop rotations, mixed farming systems and agroforestry, or a combination of these, need to be considered. In this context the interaction of biochar application with other methods warrants further investigation.

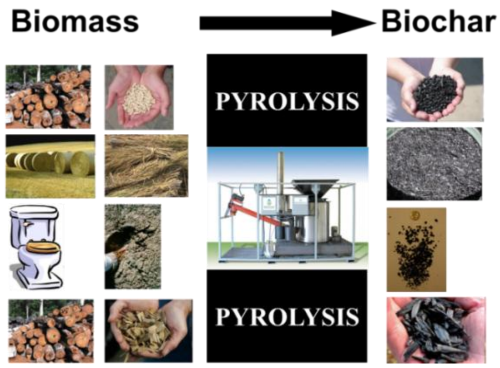


Figure 8. Examples of biomass source materials and resulting biochars.

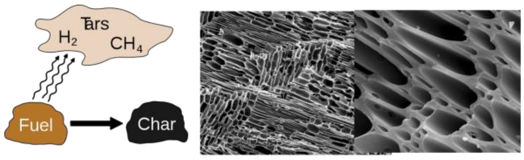


Figure 9. Left: Pyrolysis of biochar produces oils (biofuel), gas and char. Right: Electron microscope images of biochar (0.7 and 0.05 mm wide respectively).

From a climate change mitigation perspective, biochar needs to be considered in parallel with other mitigation strategies and cannot be seen as an alternative to reducing emissions of greenhouse gases. From a soil conservation perspective, biochar may be part of a wider practical package of established strategies and, if so, needs to be considered in combination with other techniques. Biochar research is in its relative infancy and as such substantially more data are required before robust predictions can be made regarding the effects of biochar application to soils, across a range of soil, climatic and land management factors.

Assessment of the SOC state in EU-27, climate change mitigation options and their impacts

The SOIL Action is under way to focus on a new assessment of the current state of SOC levels in the agricultural soils of the EU. A review of current literature on the science of SOC fluxes in relation to current land covers/uses and policies (e.g. reports, scientific papers and technical studies such as SoCo, CLIMSOIL, JRC Biochar Analysis and ENVASSO project) is on-going. The literature review is also addressing and evaluating a range of agricultural management mitigation options to stabilize or enhance SOC levels and stocks (e.g. land use change, tillage methods, cropping systems, irrigation methods, nutrient managements, cross-compliance, rural development measures, etc.) in relation to variations in soil characteristics and climatic conditions. The final results will be presented in a report that will also evaluate the negative aspects of mitigation options (e.g. increased mineralization of C from more intensive farming due to loss of land).

Soil Atlas of Africa and Latin America

The SOIL Action activities focus also outside Europe and give support to the African, Caribbean and Pacific countries.

The Soil Atlas of Africa is an international project coordinated by the SOIL Action and that involves ISRIC – World Soil Information, the FAO (Land and Water Development Division) and scientists from the ESBN and the Africa Soil Science Society. The Atlas aims to compile existing information on different soil types in easily understandable maps (national to continental scales) covering the entire Africa. While aiming to raise awareness of the importance of soil in Africa, the atlas intends to show the variety of soil characteristics across the continent, illustrate the patterns of several key soil properties at continental and national scales and specific maps to highlight areas under or vulnerable to threats such as soil erosion and salinization for example. The maps that make up this atlas are primarily derived from the Harmonized World Soil Database (HWSD) that has been developed by the Land Use Change and Agriculture Program of IIASA (LUC) and the FAO in partnership with the ISRIC – World Soil Information and with the ESBN. The database used in the Atlas is an update version of the HWSD, according to the World Reference Base for Soil Resources 2006 classification system. The HWSD original data for Africa combines existing regional and national updates of soil information (SOTER databases) with the information contained within the 1:5 000 000 scale FAO-UNESCO Soil Map of the World. The database contains thousands of polygons, each of which containing on or more soil types. The spatial resolution of the polygons varies by region depending on the source data. The best resolution represents approximately a 1:1 million map scale and can be found in Eastern and Southern Africa. Together with the publication of the Atlas, associated datasets on soil characteristics for Africa will be made available (Fig. 9). These datasets will be useful for making broad distinction among soil types and provide general trends at the global and regional scales. For example, they will be used to estimate the stock of organic carbon in Africa and for the different dominant soil types. The datasets of the Atlas will be made accessible for free downloading from the European Soil portal.

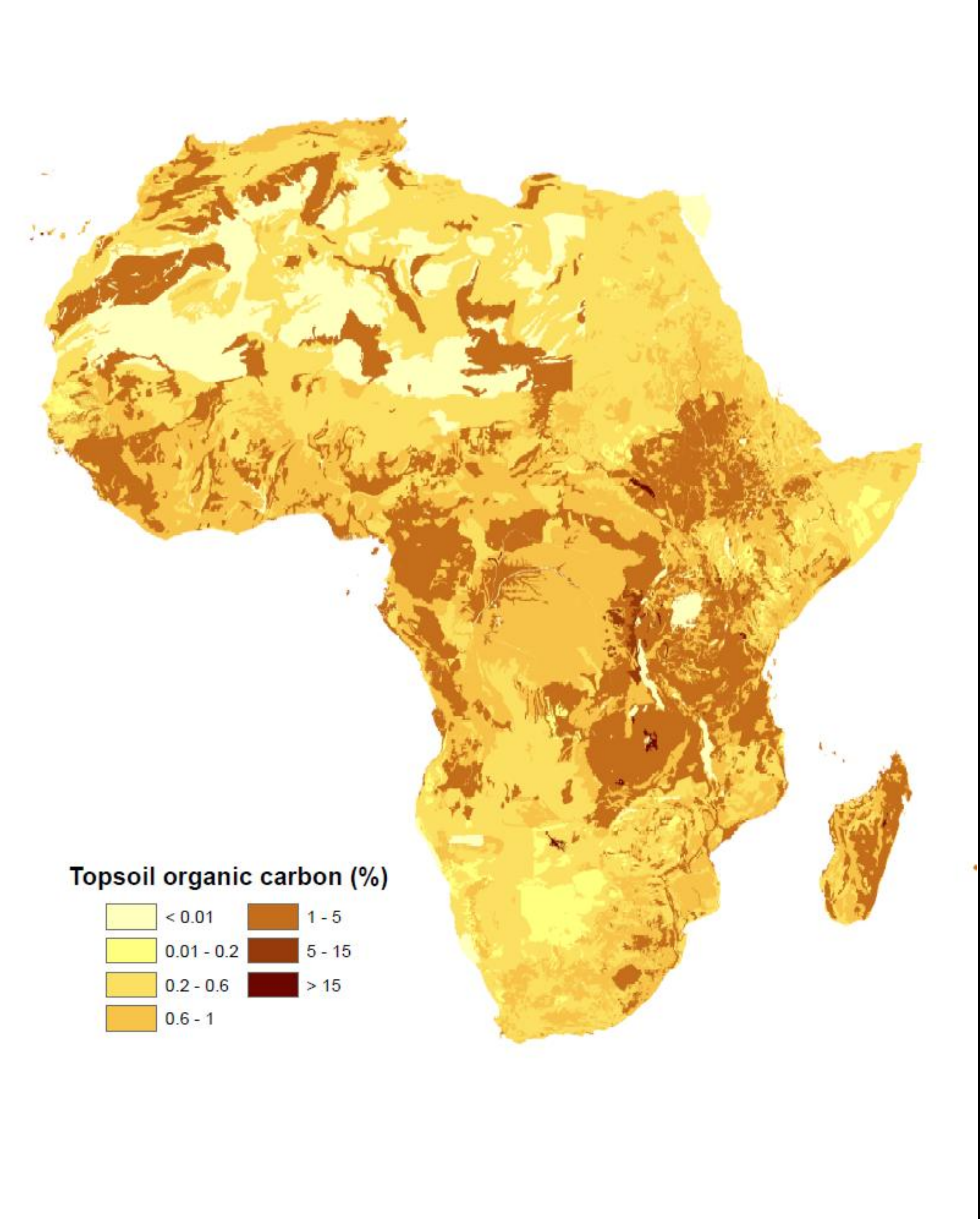


Figure 10. Percentage of organic carbon in topsoil (0-30 cm) in Africa. The values are the one of the dominant soil type of each polygon; the dominant soil type being assigned to each polygon on the basis of the greatest areal extent.

Currently, the SOIL Action is coordinating two activities in Latin America and the Caribbean: the first ever Soil Atlas of Latin America and the Caribbean (publication foreseen for late 2013) and the establishment of a Latin American network of soil scientists representing different research and survey institutions (in a similar way to the ESBN). Both are financially supported by the EUROCLIMA initiative of DG DEVCO for the regional cooperation between Latin America and the European Union in climate change issues. While the focus is on the Latin American countries (including Cuba), the Caribbean countries are also represented in the project with an active participation of some of them (Dominican Republic) and initial contacts with others (e.g. Haiti, Belize). The Atlas will be a cooperative effort between the JRC and the FAO as well as a wide representation of the soil science community from over 19 Latin America and Caribbean countries, Europe, United States and International Organizations. It will have a focus on climate change and food security, while showing the geographic distribution of the major soil types in Latin America and the Caribbean using the World Reference Base system, highlighting the key soil forming processes and drawing attention to the potentiality of and the threats to these soils. In order to provide extensive and updated information on the status of soil carbon assessments and monitoring in the region, a questionnaire was prepared and sent out to a wide network of over 100 specialists in the region. Further information on the Atlas can be found on the Soil Portal (*http://eusoils.jrc.ec.europa.eu/library/maps/LatinAmerica_Atlas/index.html*).

Hyperspectral techniques for monitoring and verifying soil organic carbon stocks in croplands

B. van Wesemael, A. Stevens and M. Nocita[1]

Abstract

Hyperspectral techniques are increasingly being used to determine chemical properties from the diffuse reflectance of visible and near infrared light from soil. In particular the applications from airborne sensors (imaging spectroscopy) provide information on the plough layer of cropland soils at very high spatial resolution. We illustrate the application of imaging spectroscopy to determine soil organic carbon in freshly ploughed croplands for two case studies: i) soil carbon content at the regional scale and ii) soil carbon stocks for a single field. At the regional scale the best results (accuracy of c. 3 g C kg^{-1}) were obtained when local calibrations were applied for each agri-geological region. Both broad regional patterns and detailed within field patterns of SOC emerged. The former reflect gradients in geology and climate, while the latter could be related to erosion and sedimentation as well as previous land use. Apart from SOC content, bulk density and rock fragment cont are required to calculate the SOC stock of the plough layer. The proximal sensing platform of the Digisoil project was used to provide this complementary data for a field within the flight line of the regional case study. Geo-electric surveys provided spatial patterns in bulk density and rock fragment content. Although the accuracy of the SOC stocks (c. 10 Mg C ha^{-1}) can still be improved, the confidence limits of the SOC stocks (48.6 ± 3 Mg C ha^{-1}) allow detecting the effects of improved agricultural techniques (e.g . zero tillage or ploughing crop residues c. 0.2-0.5 Mg C ha^{-1}y^{-1}) within 5-10 years.

Introduction

Agriculture is considered to be among the economic sectors having the greatest greenhouse gas (GHG) mitigation potential, largely via soil organic carbon (SOC) sequestration. However, it remains a challenge to accurately monitor and verify SOC stock changes. At present, monitoring and verification of SOC based on chemical analysis is expensive and time consuming, so that the

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evaluation of carbon stock changes of a field, region or country can result in a very complex total of operations (among others chemical analysis, collection of data, statistical evaluation). The large spatial variability at short distance and slow response of SOC upon changes in management practices preclude the detection of temporal changes in SOC stocks using traditional sampling and analysis methods and challenge the reliability of SOC inventories (Goidts et al., 2009). Obviously, the monitoring of key soil properties (SOC, organic N, electrical conductivity, etc.) for modeling soil processes or survey soil conditions suffers from the lack of techniques able to provide data with a high spatial and temporal resolution.

Comparatively faster than traditional measuring techniques, visible and near-infrared (VNIR) spectroscopy exploits the information carried by reflectance between 350 and 2500 nm of the electro-magnetic spectrum to measure soil properties. The emergence of portable and flexible VNIR sensors that can either be used directly in the field or mounted on tractors or in aircrafts could be the solution to provide the large amount of spatial data required for SOC monitoring. The potential of quantitative spectral analysis has been repeatedly demonstrated in soil science either in the laboratory (Rossel et al., 2006) or with remote sensors (Ben-Dor et al., 2008). VNIR spectroscopy is often called upon as a viable alternative for several routine agronomic soil analyses (e.g. Cohen et al., 2007). Due to its capacity to determine several soil properties simultaneously, VNIR spectroscopy has been applied successfully to build soil quality indicators and assess other soil functions or threats (Cécillon et al., 2008). SOC is one of the main soil chromophores and is correlated with other chromophores such as clays and iron oxide. Hence, SOC concentration can be generally determined in the laboratory with a good accuracy compared to other soil properties (see Table 1 in Rossel et al., 2006).

The SOC stock (Mg C ha^{-1}) can be calculated according to equation 1.

$$SOC = d*C*(1-RM)*BD/100 \qquad (1)$$

Where d is the depth (m), C is the organic carbon concentration (g C kg^{-1}), RM is the proportion of rock fragment by mass (dimensionless) and BD is the bulk density (kg m^{-3}). Most SOC inventories are carried out at the regional scale and focus on the spatial variation of the C content using a pedotransfer function to estimate the bulk density and a fixed soil thickness (usually the upper 30 cm). Goidts et al. (2009) evaluated the contribution of the variables of equation 1 to the overall variation in SOC stock. They found that at within fields the variation in C content had only a minor impact on the total stock variation, while within a region the overall variation was determined by the variation in C concentration (Fig. 1).

Furthermore, the overall variation in SOC stock did not significantly increase from the field to the regional scale. These findings imply that for regional scale monitoring the emphasis can be on determining the C content, but at the field scale all variables in equation 1 need to be analysed at a high resolution. We will first illustrate the application of imaging spectroscopy for C mapping of croplands at the regional scale. Then we will combine the imaging spectroscopy data acquired for a single field with other proximal sensing techniques in order to calculate a SOC stock with its confidence limits. The case studies are part of the EU 7th Framework project Digisoil.

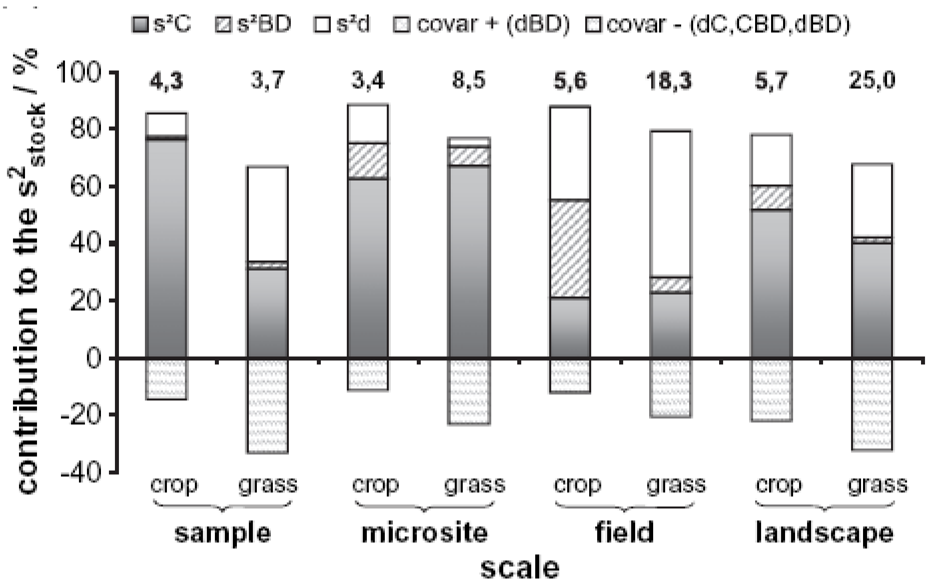

Figure 1. Sources of variability in the soil organic carbon (SOC) stock of 4 landscape units (LSU) at different scales (sample, microsite, field and landscape). S^2 C , s^2 BD, s^2d and s^2RM represent individual relative contribution (%) to the total SOC stock variance (s^2stock) of, respectively, the SOC content (C), the bulk density (BD) and the sampling depth (d), while covar are the contribution of covariances respectively increasing (+) or decreasing (-) s^2stock (the variables involved in covar are specified between brackets). The value of the SOC stock standard deviation (sstock, / Mg C ha^{-1}) is also given above each bar (after Goidts et al. 2009).

Regional SOC inventories

This case study covers a north-south transect of ~7 km wide and ~60 km long, crossing 4 of the 5 agro-geological regions of the Grand-Duchy of Luxembourg (Fig. 2). The hyperspectral data acquired from the AHS 160 airborne sensor produced the reflectance signal of the bare topsoil. This signal was then correlated with the C content of the plough layer (0-20 cm; Stevens et al., 2010). Overall we used 300 calibration samples and 100 validation samples within 50 fields.

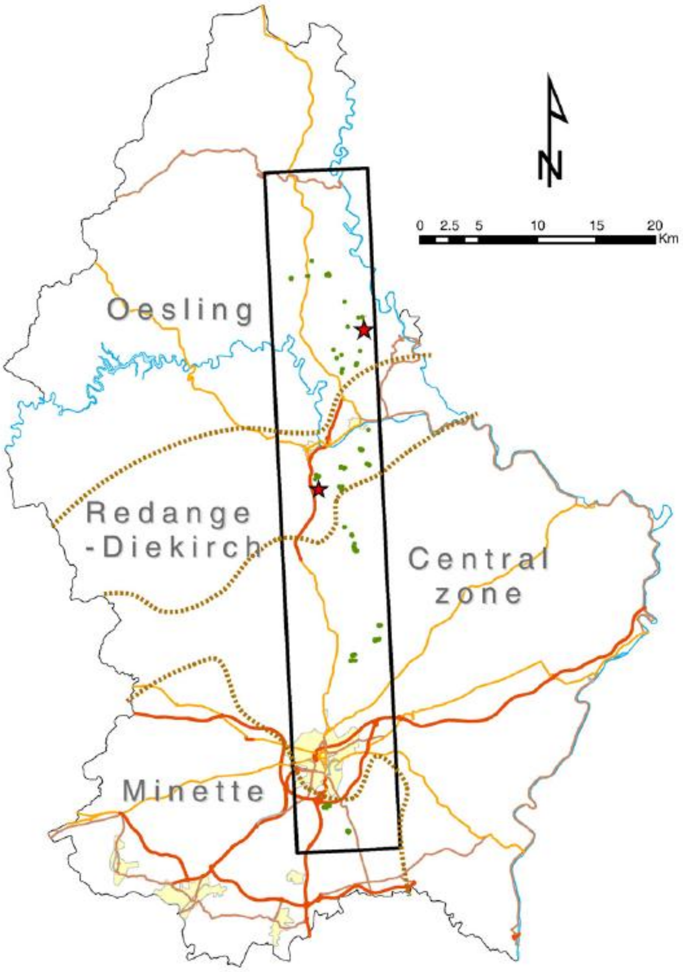

Figure 2. Map of the Grand-Duchy of Luxembourg, with sampling points (dots), flight line (bold rectangle), and limits of agro-geological zones (dotted lines). The two stars are locations for which SOC content of bare fields was mapped (see Fig. 4 ; after Stevens et al. 2010).

The local calibrations developed here demonstrated sufficient accuracy (RMSE = 4.51 g C kg^{-1}) to be applied on a pixel-by-pixel basis over the image's soil mask (Fig. 3). However, for illustration purposes, only two agricultural fields with spatial patterns of SOC are shown (Fig. 4). The SOC content in a single field of ~2.5 ha varied by a factor two (22 g C kg^{-1} to 46 g C kg^{-1}) and was found to correspond more or less with topography (Fig. 4a). High SOC content was mainly found in the concavities and lower SOC content on the shoulder and the plateau. Such patterns suggest a strong relationship between SOC content and transport of sediments induced by erosional processes under conventional tillage (deposition in concavities, erosion on convexities). Fig. 4b shows large differences in SOC content between two adjacent agricultural fields (up to 5–10 g C kg^{-1}). No information was available to explain this inter-field variability in SOC. However, the patterns may be related to differences in land management or land use history. As a matter of fact, these two small examples show that airborne imaging spectroscopy can represent a tool to improve regional SOC inventory assessments. Spatial variability of SOC is often at a scale too detailed to be captured by a coarse sampling grid. This is true at the field level, but it becomes even more critical at a landscape/regional scale. At these scales, SOC variability induced by local transfer processes (e.g. erosion) interacts with variability related to broader pedogenetic factors (climate, soil) and generates often high uncertainties in regional SOC assessments (Goidts and van Wesemael, 2007). RMSEP observed in this study (~3 g C kg^{-1}) seem still unsatisfactory in the context of SOC monitoring relative to traditional analysis methods (standard error of replicates < 1 g C kg^{-1}; Genot, pers. comm.). The accuracy still has to be improved before the technique can be exploited for SOC monitoring. Nevertheless, imaging spectroscopy allows unravelling the spatial structure of SOC at the field and regional scales.

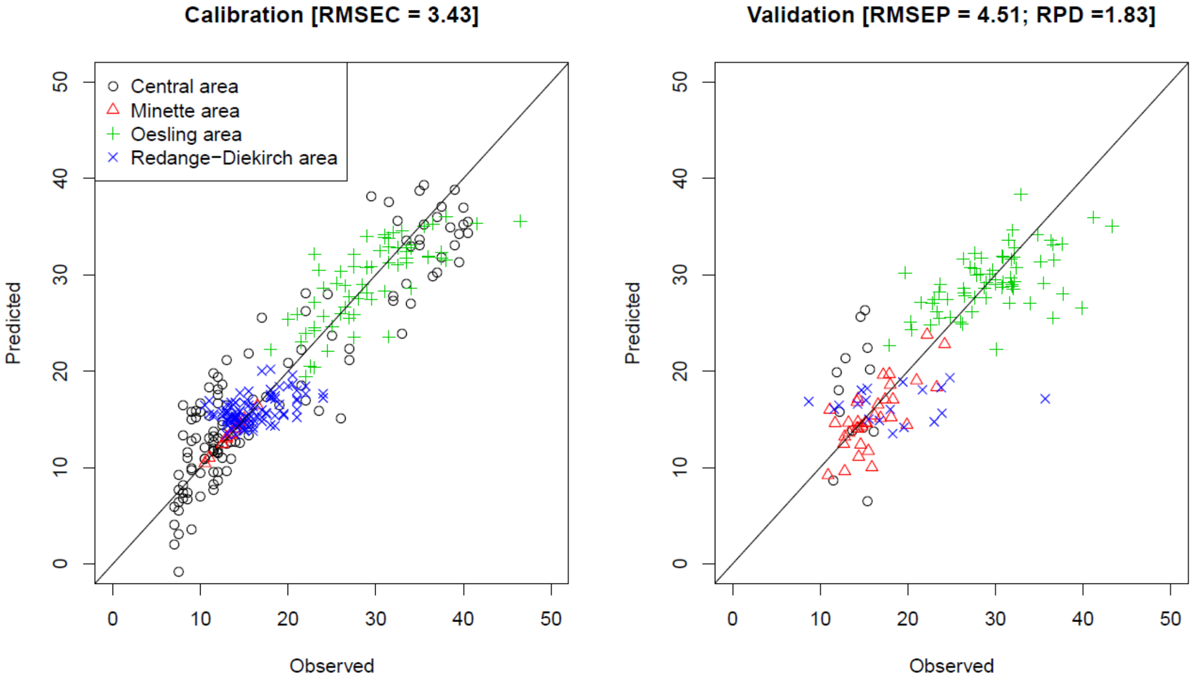

Figure 3. Plots of predicted versus observed OC (g C kg−1) in the calibration (left) and the validation(right) sets after local calibrations based on agro-geological regions (after Stevens et al. 2010).

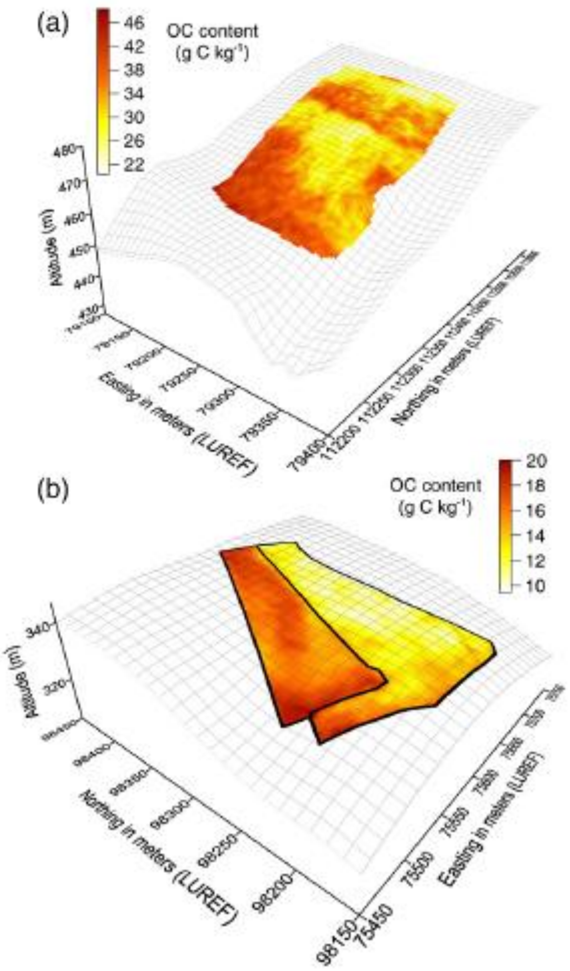

Figure 4. Maps of freshly ploughed fields, showing (a) intra-field variability of OC (g C kg^{-1}) related to topography and (b) inter-field variability of OC(g C kg^{-1}). Their positions within the study area are indicated by star symbols in Fig. 1 (after Stevens et al. 2010).

Field scale SOC stocks

At the field scale there are strong spatial patterns and vertical gradients in all variables that make the SOC stock (i.e. C content, rock fragment content and bulk density ; Fig. 5). During the Digisoil project several proximal sensing techniques have been applied in order to map the soil properties of a single field in northern Luxembourg within the flightline of the hyperspectral campaign (Grandjean et al., 2011). The rock fragment content and bulk density were determined by geo-electric surveys. The maps of these soil properties have been combined to calculate the SOC stock for the upper 20 cm corresponding to the plough layer. These maps have been validated against the SOC stocks determined using traditional laboratory analyses.

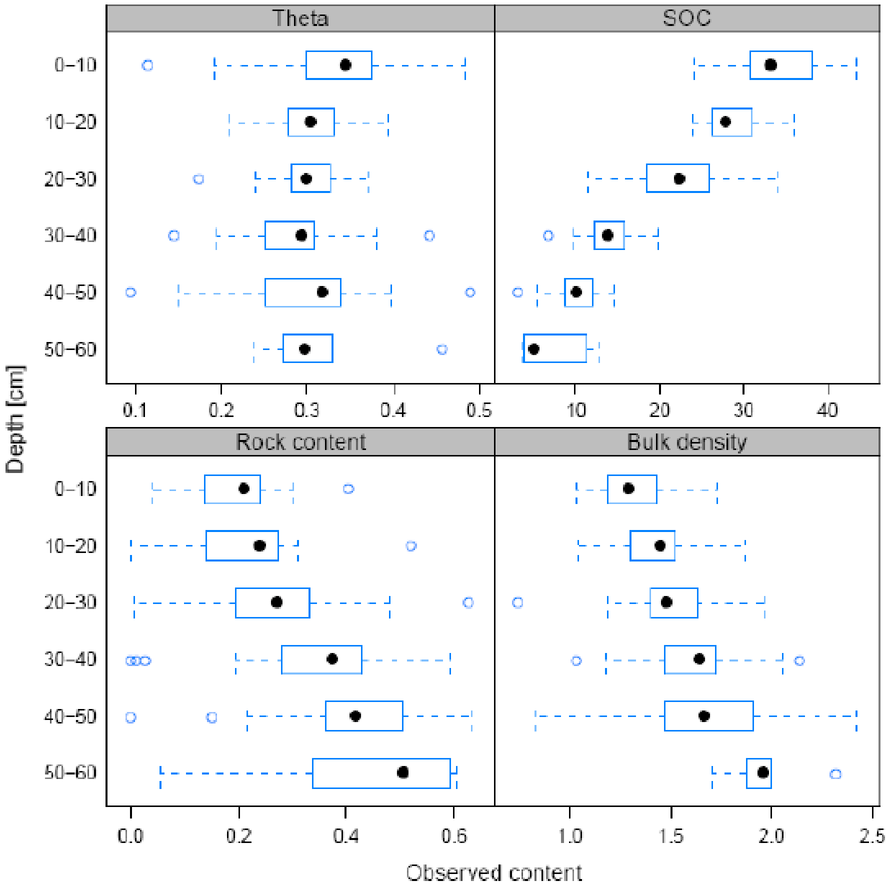

Figure 5. Box and whiskers plots of the rock fragment content by mass (dimension less), bulk density (g cm^{-3}), volumetric moisture content (m³ m^{-3}) and soil organic carbon content (g kg^{-1}) for 30 soil cores within a field (after Grandjean et al. 2011).

The map of the SOC stocks of the 0-20 cm topsoil corresponds to the plough layer (Fig. 6). As this horizon is every year well mixed, there are no vertical gradients in SOC content, stone content or bulk density. Hence, mean values of SOC content (0-20 cm), stone content and bulk density (0-30 cm) were used to calibrate the geophysical signals. In general, The SOC stock of the plough layer decreases from 70 Mg ha^{-1} in the northern part of the field to 20 Mg ha^{-1} on the southwestern margin. The low values on the northeastern field border are probably an artefact, as the rock fragment content is poorly predicted in slightly stony soils. The residuals for the validation points also indicate the largest errors in SOC stocks for the northeastern corner (points 4, 9 and 11, Fig. 6). In general, the SOC stock (0-20 cm) was reasonable well predicted with an R² of 0.3 and an RMSE of 9.41 Mg ha^{-1}. The mean value of the predicted SOC stock in the upper 20 cm is thus 48.62 ± 2.96 Mg C ha^{-1}, while the SOC stock (0-20 cm) calculated from the 30 calibration/validation points results in a value of 51.6 ± 2.37 Mg C ha^{-1}.

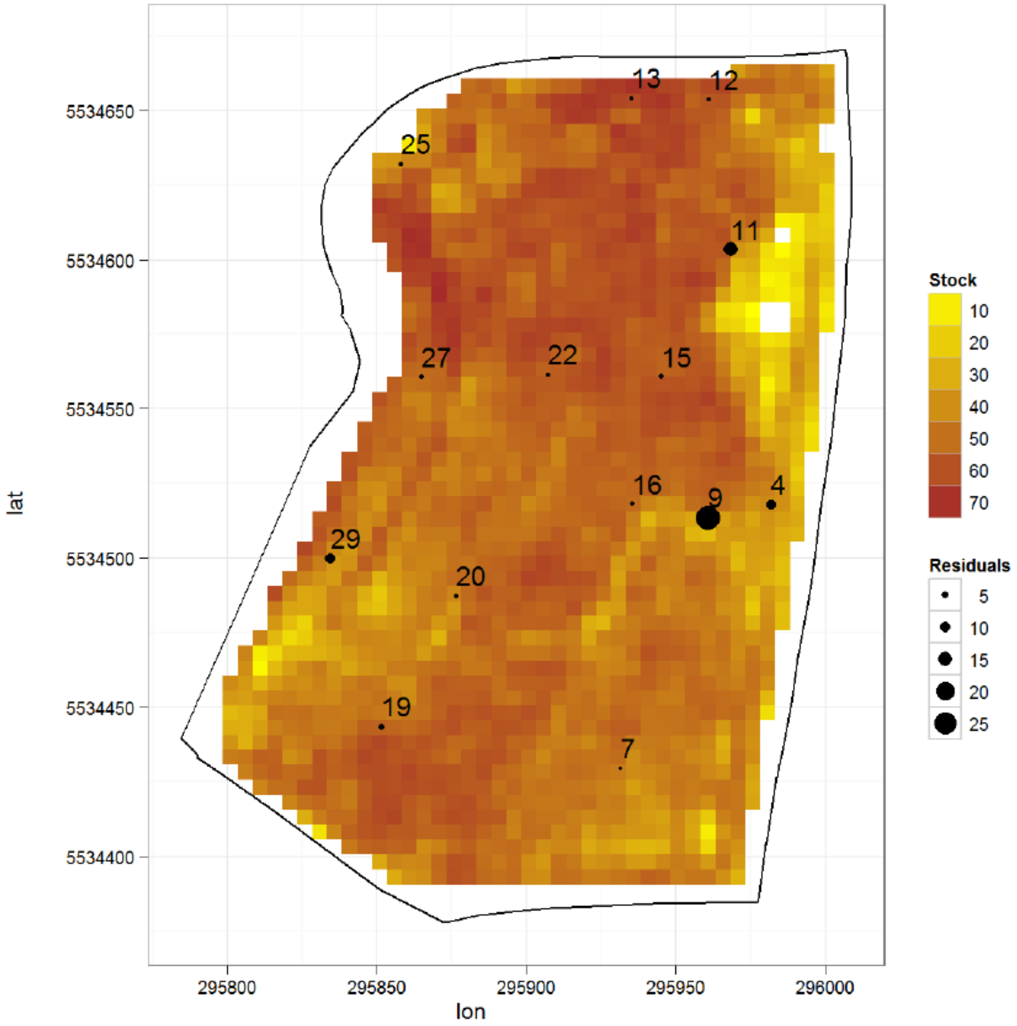

Figure 6. Map of the SOC stocks of the upper 20 cm soil layer. The values and residuals are expressed in Mg ha^{-1}. Point numbers refer to the validation points (after Grandjean et al. 2011).

Conclusions

Considering the large variation in SOC content and soil types encountered in the regional case study, the results presented here showed that airborne imaging spectroscopy can be an alternative to conventional analytical techniques. Local calibrations based on soil types and agro-geological regions appeared to be more efficient than global calibrations, due to the correlation of the strata with important chromophores like soil moisture or ferrous oxide content. The analysis of SOC content maps revealed spatial patterns related to topography and management, which confirmed the importance of both inter- and intra-field variability. The combination of maps of SOC content, rock fragment content and bulk density results in SOC stock inventories at the field scale. Apart from the imaging spectroscopy to determine the SOC content, geo-electric techniques are used to determine bulk density and rock fragment content. The Digisoil project is working on the specifications for a multi-sensor platform for routine applications.

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Crediting soil carbon sequestration in smallholder agricultural systems: what fits and what will fly?

Leslie Lipper[1], *Andreas Wilkes*[2] *and Nancy McCarthy*[3]

Increasing the organic carbon content in soils is beneficial for agricultural production and is also a means of capturing and storing atmospheric CO_2 in soils and mitigating climate change. A global effort to improve soil quality on farms has the potential to generate significant increases in both food security and climate change mitigation, given the potential number of poor farmers and land areas that could benefit. Improving farmer's management of soils for improving agricultural productivity has long been an objective of agricultural development strategies. Soil carbon sequestration has been identified by the IPCC as the largest potential source of climate change mitigation from the agricultural sector, and its inclusion in climate change policy frameworks has been debated for some time. Recognition of the potential for linking mitigation and food security objectives in policy and financing frameworks has recently been highlighted. Yet despite this enduring and multi-faceted policy interest, there has been only limited success attained in actually improving on farm soil quality, and even less in linking climate change mitigation finance to soil carbon sequestration. This paper seeks to explore the reasons for these failures, and suggest ways in which the joint food security and mitigation benefits from a global effort to improve soil quality may be captured.

The importance of improving soil quality for food security

Agricultural production is the main source of food and income for the majority of the world's poor. Most of these people are located in Sub-Saharan Africa and South Asia, where food insecurity rates are already quite high (FAO, 2009a). They are also the areas with the highest projected population growth rates for the next 50 years. Increasing the productivity and value of the farming systems of the poor is the most effective way to support their transition to food security (World Bank, 2007). Increasing the agricultural incomes of smallholder farmers allows them to make investments leading to long term improvements in livelihoods. Improving the returns to smallholder agriculture is both an efficient and equitable strategy for achieving economic growth and poverty reduction in countries with highly agricultural based economies – as in South Asia and Sub-Saharan Africa (World Bank, 2007; Thirtle et al., 2003).

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Poor soil quality is one of the main constraints to improving agricultural productivity for many smallholder farmers in developing countries (Stocking, 2003; Lal, 2004). Poor land management practices – such as continuous cropping with no fallowing or fertilizer inputs, or cropping on sloping lands generating high rates of erosion – have depleted natural soil fertility and degraded soil quality (Lal, 2004; Cassman, 1999). The impact is declining productivity and increased vulnerability to natural hazards such as drought, floods or pests and diseases. Depleted soils have little capacity to store water or house beneficial organisms – which are important mechanisms for coping with drought and building resistance to pests and diseases.

The importance of soil carbon for climate change mitigation

According to the IPCC 4th assessment report (Smith et al., 2007) the technical mitigation potential of agriculture from 2005 to 2030 totals around 5500-6000 Mt CO_2eq. Of this, around 89%, or around 4895-5340 Mt CO_2eq, is from reduced soil emissions of CO_2, through improvements in grazing land management, cropland management, restoration of organic soils and degraded lands, bioenergy and water management (Smith et al., 2007). To put this in perspective, Chen et al (2011) estimate that emission reduction commitments made by Parties to the UNFCCC up to the end of negotiations in Cancun in December 2010 would leave the world with a shortfall of 10,000-14,000 Mt CO_2 eq compared to emission reductions required to limit global warming to 2 degrees Celsius by 2020. While the economic potential of agricultural mitigation to 2030 has been estimated to be only 28%, 46% and 74% of the total technical mitigation potential at $20, $50 and $100 per tonne CO_2 (Smith et al., 2007), the fact that agricultural practices which sequester soil carbon are technically mature and ready for deployment means that agriculture has a strong potential to play a non-marginal role in early action to change the global emissions path while other unproven and more costly mitigation technologies are being developed (Lal, 2004).

Among the agricultural mitigation practices assessed by the IPCC, a range of practices grouped under the category of cropland management have the highest technical potential for soil carbon sequestration, estimated to be more than 1400 Mt CO_2eq by 2030 (Smith et al., 2007). Cropland management includes improving agronomic practices, such as introducing improved crop varieties, use of improved fallows, green manuring and cover crops, which increase soil carbon stocks. Integrated nutrient management (improving fertilizer application and timing), introducing nitrogen fixing cover crops, water management (including soil and water conservation practices), tillage management (minimum soil disturbance and incorporation of residues), as well as agro-forestry practices are also included in the category of cropland management. The potential for sequestering carbon from adoption of these practices is global, with particularly high potential in East Africa and South and Southeast Asia (Smith et.al., 2007).

Improved grazing land management is another major group of practices that can generate globally significant levels of soil carbon sequestration, with an estimated technical mitigation potential similar to cropland management, i.e. >1400 Mt CO_2eq by 2030 (Smith et al, 2007) At around 3350 million ha (more than twice the global arable land area), grazing lands present a huge potential for sequestering carbon. According to Smith et al (2007), potential gains are particularly high in almost all regions of Africa and Asia, as well as South America. Increasing soil carbon in grasslands areas can be achieved through the introduction of improved grazing management, reducing or eliminating the occurrence of fires, and introducing improved fodder grasses or legumes. In addition, avoiding conversion of grasslands to croplands is a significant potential source of emission reductions.

Restoration of degraded lands refers to restoring soil organic carbon in areas which have been depleted. FAO (2007)'s analysis of the distribution of the soil carbon gap and of cropland suggests that 15% of total global croplands are located in areas with a medium to high potential for soil carbon sequestration. Measures to restore degraded lands include many of the same practices under improving cropland and grasslands management – essentially increasing organic inputs to the soil, reducing or eliminating tillage, increasing cover and residue incorporation, and the introduction of agroforestry and silvo-pastoral systems. In other cases the use of soil and water conservation practices, including terracing, bunds, and contour stripping are also used in restoration activities.

A fourth major potential source of soil carbon sequestration identified by the IPCC is restoration of organic soils, with an estimated technical potential of more than 1300 Mt CO_2eq by 2030 (Smith et al., 2007). These are peat or wetlands areas that have been drained and converted to agricultural production. Two major areas of importance for this type of activity include South East Asia and the Amazon Basin. The main method of reducing GHG emissions is avoiding conversion of such lands to agricultural production. Other practices to minimize emissions include avoiding row crops and tubers, avoiding deep ploughing, and maintaining a shallower water table (Freibauer et al., 2004).

Aside from these potential sources of soil carbon sequestration assessed by the IPCC, there is also considerable soil carbon sequestration potential that may be captured by reducing emissions from deforestation and forest degradation as well as the conservation, sustainable management of forests and enhancement of forest carbon stocks (e.g. REDD+). Although the major source of emissions reduction benefits in the REDD+ category come from the above-ground carbon sequestered in trees, the potential soil carbon benefit from avoided conversion of forest to agricultural lands is large, accounting for around 10-30% of total carbon emissions from tropical deforestation (Don et al., 2011). Since agricultural expansion is a major driver of deforestation, increasing the intensity of agricultural production – including by adoption of many of the sustainable land management practices listed in the preceding paragraphs – has potential to reduce agricultural emissions while also creating supportive conditions for forest carbon sequestration (Angelsen, 2010).

Synergies between agricultural, food security and mitigation from improving soil quality

The list of practices under the various categories of soil carbon sequestering activities above is remarkably similar to those identified as necessary for sustainable land management to improve agricultural production (Lal, 2004; FAO, 2009b; FAO, 2010). The major exceptions are avoided conversion of organic soils and avoided deforestation and forest degradation, which have negative impacts on agricultural production by reducing areas for crop and livestock production. However even these activities could have synergies for agricultural development and food security if structured to include intensification on existing agricultural lands (Angelsen, 2010).

In looking for synergies between agriculture, food security and mitigation, it is necessary to have an understanding of the benefits of improvements to soil quality for each objective under varying circumstances, as well as the costs of making such improvements. The analysis also requires some consideration of prioritization of objectives between agricultural growth, food security, and climate change mitigation. For low income, agriculture- dependent developing countries, agricultural growth for food security is a key priority, increasingly recognized in national development strategies and plans as well as agricultural sector strategies (Future Agriculture Consortium, 2011). Mitigation from the agricultural sector is not likely to be a top policy priority per se, although achieving lower emissions growth patterns is important, particularly since it may be linked to financing for mitigation, as well as conditions on development assistance.

Identifying locations, farming systems and farming groups where increasing soil quality is likely to have the greatest impacts on agricultural productivity is a first step in identifying potential synergies. The main benefits to smallholder farmers of adopting soil improving sustainable land management practices include increases in yields per hectare, increases in yield stability over time due to greater resilience, and reduction in production costs (FAO, 2009b; FAO, 2010). The degree to which any one of these three types of benefits can be obtained by individual farmers adopting sustainable land management practices is quite variable, depending on the specific agro-ecological conditions they are operating under, the past history of land use, the socio-economic environment (including input and output markets, and policies affecting access to land and other inputs), as well as specific household characteristics.

Nevertheless, we can identify some general conditions where agricultural benefits to soil improvements are likely to be highest. Key issues to consider are climate, soil type, and current use and quality of the land. For example, a recent summary of the literature (Branca et al., forthcoming) on the impacts of improved cropland management on agricultural yields indicates that higher average yield gains are obtained from adopting sustainable land management practices in dry areas – in both cool and warm climates – compared with moist areas. One of the benefits of increasing soil organic carbon is increasing the capacity of the soil to absorb and store water. This creates greater capacity to withstand drought, and also reduces flooding and soil erosion since runoff is reduced. These impacts on water availability, together with associated fertility impacts, generate significant increases in yields moving from conventional to sustainable land management practices. In humid areas, positive yield effects are also gained, but at lower rates of increase compared to yields in conventional systems. Soil types and level of degradation are also key determinants. Sequestration rates are generally higher on heavier clay soils compared with sandy soils, and moderately to lightly degraded soils generally have higher sequestration rates with the adoption of sustainable land management, at least in initial phases (Lal, 2004).

Grazing intensity is one of the main factors affecting soil carbon stocks in grazing lands outside hyper-arid and arid areas. Compared to heavy grazing, moderate grazing has generally been found to increase organic matter inputs to soils and therefore increase soil carbon stocks (Conant and Paustian, 2002). Moderate grazing is also often associated with higher biomass productivity and richer biodiversity in grasslands, though this depends also on the site-specific grazing history, vegetation types and climate variables (Milchunas and Lauenroth, 1993). These benefits may translate into increased livestock health and productivity (Kemp and Michalk, 2007), though the short-term economic optimum for livestock keepers often involves grazing at levels that deplete above- and below ground resources, since total animal weight gain per unit area is often higher at higher stocking densities (Jones and Sandland, 1974).

Essentially this analysis suggests that synergies between mitigation and agricultural growth for food security are likely to be the rule with adoption of sustainable land management. However the degree to which soil improvements generate food security versus sequestration benefits varies. Sustainable land management practices in drylands are key to food security, with relatively smaller sequestration benefits per hectare. Figure 1 below summarizes some examples of activities and their relative contribution to mitigation and food security (defined as agricultural productivity increases in this context).

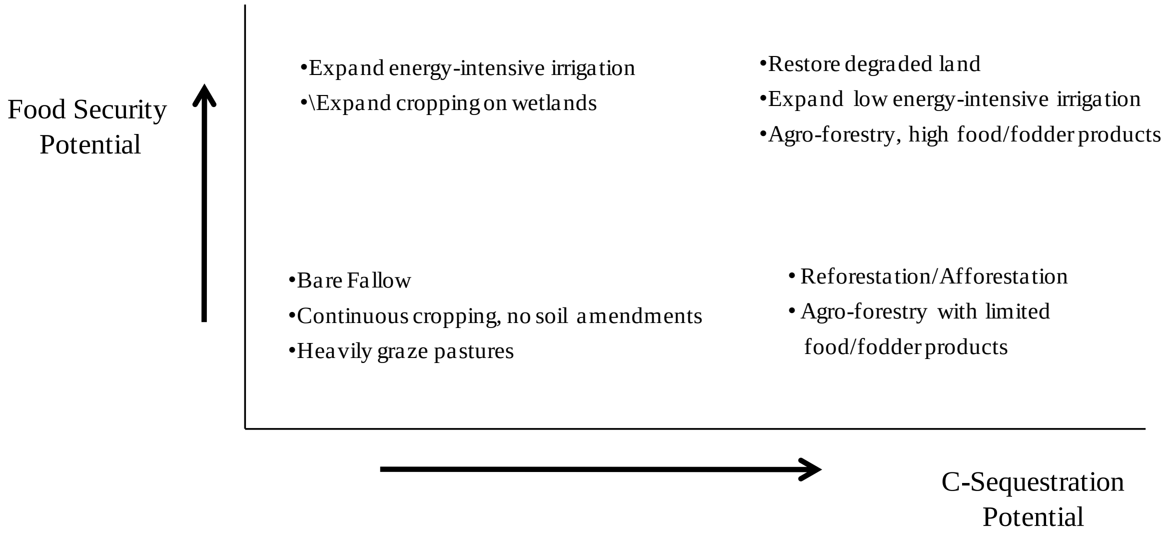

Figure 1. Examples of Potential Synergies and Trade-Offs (Source: FAO, 2009b)

Barriers to adopting practices that improve soil quality

Despite the agricultural benefits that farmers may obtain from adopting sustainable land management practices and fairly extensive campaigns to support their dissemination, the adoption rate amongst small farmers has been quite low. A recent summary of the literature has highlighted key constraints (McCarthy et al., forthcoming).

Unsurprisingly, one of the main barriers to adoption is costs, including three major categories of costs: initial investment costs, annual operating costs, and opportunity costs of income foregone by undertaking the activities needed for improving soils (FAO, 2009b; FAO, 2010). A commonly reported major problem is financing the initial costs of adoption of a system that has net positive benefits but only over the long term. In some cases investment costs can be quite significant (e.g. soil and water conservation infrastructure) and also involve considerable labor inputs (FAO, 2009b; FAO, 2010).

Opportunity costs are probably the most important category of costs that have not been well understood or addressed, and are likely to be a major cause of low adoption rates. The issue is the amount of time it takes to obtain a higher return to agriculture than obtained under the conventional, or baseline practice. During the transition between systems, farm income can even be negative for some periods, particularly where the new system requires activities, such as reduced stocking levels or fallowing to restore degraded lands. These kinds of opportunity costs are likely to be highest where degradation is high and longer recovery periods required (FAO, 2009b; FAO, 2010).

Another major barrier to the adoption of sustainable land management activities is the lack of enabling institutions, such as extension services, machinery and input supply chains and ways of managing collective resources (FAO, 2010). Achieving the adoption of sustainable land management practices on a broad basis will require agricultural policies that provide incentives for effective input use and crop diversification which in many cases are lacking. While individual financing at the farm level is needed to support transitions to systems that generate higher soil quality, without government investments to create supporting conditions, adoption will still be quite constrained.

Opportunities for using mitigation finance to support transitions to sustainable land management in smallholder agricultural systems

The mitigation value of activities that reduce emissions may be rewarded through the emerging regulatory and voluntary frameworks being established. Carbon markets established under cap and trade regimes, such as the Clean Development Mechanisms (CDM) under the Kyoto Protocol, are one potential source of such financing. In the context of developing country agriculture, emission reductions provided through carbon sequestration could potentially be credited to offset emission reductions in other sectors. However soil carbon sequestration from agricultural sources is not an allowable source of emissions reductions under the CDM at present. Sequestration from afforestation and reforestation is allowed, however even these have been restricted to a maximum of 11 Mt CO_2eq in the first commitment period (Larson et al., 2011). Agricultural, including soil carbon, offsets are eligible in some sub-national regulatory schemes (e.g. Alberta offset credit system), but at present the scale of these schemes is relatively limited, and at this stage such sub-national systems tend not to accept offset credits generated in developing countries. Because of restrictions on eligibility under the CDM and other compliance schemes, agricultural offsets are mostly restricted to the voluntary market, where they account for a small proportion of total credits generated (Hamilton et al., 2010). The voluntary market in turn is very small compared to global compliance markets (Kossoy and Ambrosi, 2010; FAO, 2009) and to the scale of emission reductions required globally. Thus, regardless of the future developments in global, national and sub-national offset markets, this form of mitigation finance is unlikely to become a major channel of new funds for smallholder agriculture soil carbon sequestration in the near term.

Some lessons from early pilot activities indicate that pilots to develop new classes of project are expensive, although the returns for project participants may potentially be high. Soil carbon accrues slowly over time, while upfront investment costs are often high, making such projects unattractive compared to many other investment options. Looking beyond small-scale pilots, payments for carbon sequestration to smallholder farmers achieved on any large scale will need to be embedded in government programs. On the one hand, this is because a significant proportion of investment costs in agricultural carbon projects occur upfront, while private buyers of carbon projects are often unwilling to bear the risks of upfront investment. On the other hand, government-funded agricultural extension systems provide an institutional basis for upscaling adoption of agricultural activities.

In this regard, one of the more interesting possible future developments for mitigation financing for developing country agriculture is through the nationally appropriate mitigation actions (NAMAs) that are currently under discussion in the UNFCCC process. The NAMA concept is still evolving and to date covers a wide range of financing and crediting proposals, from offset trading markets to public sector payment programs. At a general level, it has been suggested that NAMAs could provide an over-arching structure for 3 different types of action differentiated by source of funding: (i) unilateral actions undertaken by developing countries without support from developed countries; (ii) actions supported by developed countries; and (iii) actions that generate tradable carbon credits.[4]

Thus NAMAs could essentially be structured to be a public sector investment into building long term capacity for accessing a new source of finance for agriculture, be it through carbon markets or public sector incentives for mitigation (including international public sector sources such as the Cancun Fund). Since NAMAs are to be proposed by Parties to the UNFCCC, they can consider agricultural and land use sector development priorities, and integrate with national agricultural programmes. In fact, of the NAMAs submitted by non-Annex 1 countries to the UNFCCC in 2010 *(http://unfccc.int/meetings/cop_15/copenhagen_accord/items/5265.php)* 32 relate to agriculture, indicating strong developing country interest in accessing support for agricultural development through NAMA implementation mechanisms.

Nevertheless, despite interest in the potentials of the voluntary market, the possibility of a reformed CDM in which soil carbon is eligible, and the potential of NAMAs, it is important to bear in mind that total estimated mitigation finance is only a small share of the overall investments required by developing country agriculture as a whole (FAO, 2009b). Market and non-market mechanisms that link with other sources of public and private finance will be needed to generate the funding required.

Key issues to overcome in promoting agricultural mitigation actions

In the negotiations over inclusion of land use offsets in the CDM, it became clear that land use offsets were perceived as less credible than other sources of offset supply. Two main issues with soil carbon sequestration were (a) the risk that soil carbon is not sequestered permanently, so the impacts of mitigation actions on atmospheric concentration of CO_2 would not be permanent, and (b) the perceived high uncertainty associated with measuring agricultural GHGs. Thus, no matter whether agriculture is to be supported through tradable credits or public mitigation finance, agricultural

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[4] http://unfccc.int/files/meetings/ad_hoc_working_groups/lca/application/pdf/mitigation1bii140808_1030.pdf (page 4 referring to negotiation text page 94: alternatives to paragraph 75, alternative 2)

mitigation actions have to ensure a high level of credibility through quality standards in order to be accepted. Land use based agricultural credits are still in their very early stages. Recently, uncertainty in international and national regulatory contexts has contributed to a low value for many voluntary credits, and for land use credits in particular, possibly due to concerns with credibility (Conte and Kotchen, 2009). Achieving a significant level of financing for agricultural mitigation will require national and international stakeholders to cooperate in developing widely accepted protocols that ensure the credibility of agricultural emission reductions while also reducing the barriers to smallholder participation.

Regarding the risk of non-permanence, the solution adopted under the CDM was to create a special class of emission reduction certificates, known as temporary CERs, or tCERs, while other industrial emission reductions generate lCERs (long-term CERs). In addition, the EU ETS, one of the largest trading systems, excluded tCERs outright, deeming them incomparable with lCERs. The effect of these decisions was to segment the market, placing land use projects in a market segment for which there was limited compliance demand, and thus tCER prices are lower than for lCERs. An alternative solution to the risk of non-permanence has been developed in and embraced by the voluntary market. The Voluntary Carbon Standard (subsequently renamed Verified Carbon Standard - VCS) pioneered the use of a risk buffer fund. Each project is assessed against risks of non-permanence and a corresponding proportion of the credits are placed in an untradable risk buffer fund. Since different projects face different levels of risk, overall risk of non-permanence is managed by hedging the risks of different projects against each other. This mechanism has subsequently been adopted by some other voluntary standards.

Regarding the credibility of emission reduction estimates from agricultural land use projects, early experimentation through voluntary markets has provided some indication of possible options to address issues of credibility. There are several sources of uncertainty associated with soil carbon sequestration activities that MRV systems for GHG accounting must explicitly or implicitly address: (i) uncertainty over whether or not an activity is implemented and an accurate accounting of the land area involved; (ii) uncertainty arising from emission factors attributed to mitigation actions, particularly in heterogeneous agricultural landscapes; (iii) uncertainty due to lack of scientific documentation of the impacts of management practices on non-CO_2 emissions associated with carbon sequestering processes.

One of the biggest constraints to building viable agricultural MRV systems in developing countries is the lack of research establishing a credible basis for associating changes in soil carbon sequestration with changes in agricultural activities. Some early agricultural mitigation programmes (e.g. under the Alberta offset system, VCS and Climate Action Reserve) give excellent examples of the protocols for estimating emission reductions that can be set up when a sufficient basis of research information is available.

In the absence of such information, however, there are several options for addressing the problem. One approach would be to conduct very intensive field measurements of soil carbon changes with changes in land practices and to issue credits based on actual measured changes. This approach is not likely to be widely applied, mainly because extensive direct measurements are quite expensive to conduct. Another option is combine detailed activity data with conservative (e.g. IPCC Tier 1) default values for crediting soil carbon sequestration. This would have the advantage of low measurement costs, but potentially low accuracy. Starting with a conservative, simple approach would allow for the development of methods via “learning by doing” and increasing the research basis alongside early mitigation actions. Prioritizing areas for soil carbon crediting by the ease with which changes in soil carbon can be detected - e.g. areas where a high “signal to noise” ratio between changes in soil carbon and existing stocks are found would be one way to improve accuracy with this method (McCarthy and Lipper, 2010). One potential objection to this approach is that a very conservative approach may not yield sufficient emission reduction credits to make agricultural sequestration feasible for crediting, since the reduction in the value of the emission reductions would be greater than the reduction in transactions costs. Furthermore, field measurements of soil carbon in a smallholder project setting would be subject to a large set of influencing factors and uncertainties, and would not necessarily be an effective way to reduce the uncertainty of soil carbon sequestration estimates.

A third option – that is being used in the development of methodologies for several voluntary carbon standards – is to use a more sophisticated biogeochemical process model, such as Century, Roth-C or DNDC, which is combined with a limited set of field measurements used to parameterize and validate the model. The difficulty with the use of such models is that although it may be possible to validate the general outputs of the model, long-term experimental data with which to validate model predictions for specific management changes is lacking for most management practices in most agroecosystems worldwide. Discussion on early experiences with this approach has begun (e.g. Olander and Haugen-Kozyra, 2011), but as yet there are no agreed protocols to ensure transparency in the ways in which such models are manipulated in the process of operation. Further research is needed to validate models across varying agro-ecosystems and farming systems. This will require careful consideration of sampling design, rigorous implementation of study protocols and long term research sites. This is a prime example of where public funding can support the development of agricultural mitigation schemes. Ideally a set of coordinated long term research monitoring plots for soil carbon under transitioning farming systems could be established and maintained by public sector research institutions – including potentially FAO.

To date, most applications of modeling approaches have occurred in the farming systems of developed economies, where regulatory requirements ensure that farms maintain relatively comprehensive farm records which can provide the basis for activity monitoring data. In most developing countries, such regulatory requirements and other capacities required for accurate activity monitoring often do not exist. Insufficient attention has been given to the requirements for precise activity monitoring, although some smallholder pilot projects are developing early examples of monitoring procedures. Irrespective of whether financial support derives from carbon markets or public climate mitigation finance, credible activity monitoring systems are required. Activity monitoring for up-scaled adoption would further have to be based on existing agricultural M&E (monitoring and evaluation) systems. Analysis of an existing agricultural M&E system suggests that they may provide a credible basis for MRV of agricultural mitigation actions where (i) their procedures are encoded in explicit rules that are transparently communicated, (ii) they include provisions for quality control and quality assurance, and (iii) where they are based on institutional arrangements that provide accountability in ways appropriate to the national context (Wilkes et al, 2011). Developing country M&E systems are insufficiently documented to allow an assessment of the extent to which existing systems meet these criteria.

Conclusions: What fits and what will fly?

In thinking about the role of mitigation in agricultural production systems it is important to consider that projected increases in agricultural production are a necessity for reaching global food security and poverty reduction objectives, and these increases will entail an overall increase in agricultural emissions. This is born out in projections of agricultural related emissions from developing countries. Imposing a mitigation requirement on the development of livelihoods for the poorest people on the earth is neither feasible nor desirable. However working to identify and support development pathways that generate lower emissions than a “business as usual” high energy development pathway is quite desirable. The key role of mitigation finance in this context then, is to support the development of low emission development pathways, using mitigation finance to support transformations of smallholder agricultural production systems that generate more secure and profitable livelihoods that are adapted to climate change and contribute to the mitigation of climate change.

Allowing soil carbon sequestration emissions reductions in the CDM and building a program of work to support development of appropriate MRV systems is an issue being raised in the UNFCCC process. Agriculture is also on the agenda of the SBSTA (Subsidiary Body for Scientific and Technological Advice of the UNFCCC) meeting scheduled for June 2011 and these issues are likely to be addressed. However the uncertainty in the overall international system is a much more pressing issue, with significant implications for the future of any mitigation finance. It may be that a wider range of agricultural offsets (including soil carbon) are eligible for the CDM under a post-2012 global climate agreement. Alternatively, if no global agreement is achieved, various national or regional cap and trade systems may be established, expanded and possibly linked.

Early experiences with agricultural mitigation pilot projects in the voluntary market suggests that mitigation finance will only make a meaningful contribution to the achievement of agricultural development objectives in developing countries if it is linked to public finance, and embedded in existing programs for promotion and monitoring of adoption. In this respect, early small-scale pilot experiences are essential for working out feasible approaches to credible estimation of emission reductions. Mechanisms, such as NAMAs, which have potential to enable linking of mitigation action support with markets and non-market sources of climate finance have potential to contribute alongside upscaled public finance to meeting the multiple objectives of sustainable land management.

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RESEARCH NEEDS FOR FORESTRY AND ENVIRONMENT POLICIES

JRC activities in forest monitoring related to REDD+

F. Achard, P. Mayaux A. Bouvet, A. Brink and B. Desclée[1]

This chapter covers the recent developments undertaken by JRC for estimating tropical deforestation from Earth observation data. For the UNFCCC process it is important to tackle the technical issues surrounding the ability to monitor and report greenhouse gas emissions from deforestation in developing countries. Remotely-sensed data are crucial to such efforts. Recent developments in monitoring of tropical forests from Earth observation can contribute to reducing the uncertainties in estimates of carbon emissions from deforestation. Key requirements for implementing future monitoring programs are international commitment of resources to ensure regular pan-tropical coverage by satellite remote sensing imagery at a sufficient level of detail, access to such data at low-cost, and consensus protocols for satellite imagery analysis.

Role of tropical deforestation in global carbon emissions

Tropical deforestation is estimated to total approximately 13 million hectares per year in the period 2000 - 2010 compared to 16 million hectares per year in the period 1990 - 2000 (FAO, 2010). The net loss of forest area globally has been significantly reduced from 8.3 million hectares per year between 1990 and 2000 to 5.2 million hectares between 2000 and 2010. This reduction of net loss is largely due to an increase in afforestation, natural forest regrowth, reforestation, and forest plantations. However, the global rate of gross deforestation, mainly the conversion of tropical forests to agricultural land, is still alarmingly high and has significant impacts on global climatic change and biodiversity issues.

Deforestation in the tropics is thought to be a major contributor to greenhouse gas emissions. Deforestation causes a large loss of carbon stock per unit area relative to other practices in forests (e.g. logging) that may only result in forest degradation and lower loss of carbon stock (Asner et al., 2010). Emissions from tropical deforestation, forest and peat degradation are currently estimated to 15 % of the world's anthropogenic greenhouse gas emissions, mainly through CO_2 emissions (range 8-20%) (van der Werf et al., 2009). For the period 1997-2006 global net carbon emissions resulting from land use changes, predominantly deforestation in the tropics and peat degradation, have been

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estimated at 1.5 GtC yr^{-1}; 1.2 GtC yr^{-1} from deforestation and forest degradation and 0.3 GtC yr–1 from peat degradation.

On the other hand old-growth tropical forests store carbon at an estimated rate of 0.5 t C ha^{-1} yr^{-1} (Lewis et al., 2009), which leads to a carbon sink of 1.3 Gt C yr^{-1} across all tropical forests during recent decades. In complement to carbon emissions, tropical deforestation weakens also this natural sink capacity.

To obtain accurate estimates of emissions from land use changes in the tropics several components must be estimated accurately, in particular: the area of forest cover changes, the initial carbon stocks (above and below ground biomass and soil organic matter) in forests before deforestation or forest degradation and the processes of changes in the carbon stocks within forests caused by deforestation, gains from growth and losses from degradation and other processes (Ramankutty et al., 2007). Accurate figures of forest cover changes are needed to reconcile estimates of land use change emissions from different sources which are presently calculated from different data bases: Houghton (2005) used deforestation figures from the FAO Global Forest Resources Assessment 2000, while JRC (Achard et al., 2004) and DeFries et al. (2002) used their own remote sensing derived deforestation estimates.

Reference data on biomass and accepted procedures to estimate the fluxes are equally essential (Keith et al., 2009). The full potential of satellite remote sensing imagery for biomass monitoring is yet to be realized. A new challenge lies in estimating change in carbon stocks directly from remote sensing and then linking the information on forest carbon stocks and satellite derived maps of changes in forest cover to the estimation of emissions (Baker et al., 2010). Data on forest carbon stocks at both continental and global scales is improving (Saatchi et al., 2011). It has been suggested that lack of funding limits efforts to reduce uncertainties of estimates of biomass (Houghton et al., 2009).

Methodological guidance for activities relating to the REDD+ mechanism of the UNFCCC

At the UNFCCC COP-15 held in Copenhagen in December 2009, the need to provide incentives for REDD was for the first time mentioned in the final declaration of the Heads of State and governments, referred as Decision 2 of the COP-15 (2/CP.15). Decision 4/CP.15 provides methodological guidance for activities relating to reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries, the so-called “REDD-plus” extended activities (UNFCCC, 2009). Decision 4/CP.15 requests “developing country Parties, … (a) to identify drivers of deforestation and forest degradation resulting in emissions and also the means to address these; (b) to identify activities within the country that result in reduced emissions and increased removals, and stabilization of forest carbon stocks; …”. Decision 4/CP.15 further recognizes that forest reference emission and forest reference levels should be established transparently taking into account historic data and national circumstances. The core of Decision 4/CP.15 on methodological guidance deals with the establishment of “robust and transparent national forest monitoring systems and, if appropriate, sub-national systems” with the following characteristics:

(i) combination of remote sensing and ground-based forest carbon inventory approaches
(ii) transparent, consistent, as far as possible accurate estimates taking into account national capabilities and capacities;
(iii) results available and suitable for review as agreed by the Conference of the Parties;

Decision 4/CP.15 also invites “Parties in a position to do so and relevant international organisations” to enhance the capacities of developing countries to collect and access, analyse and interpret data, in order to develop estimates and to enhance coordination of the activities of the different stakeholders. Parties are requested “to use the most recent Intergovernmental Panel on Climate Change (IPCC) guidance and guidelines, as adopted or encouraged by the COPs, as appropriate, as a basis for estimating anthropogenic forest-related greenhouse gas emissions by sources and removals by sinks, forest carbon stocks and forest area changes”. The definitions of forest and deforestation agreed under the UNFCCC will serve of reference for the future mechanism. There is no official definition of forest degradation but, in a REDD-plus context, it corresponds to a loss of carbon stocks in forests remaining forests due to human activities.\

A monitoring activity in support to a potential REDD-plus mechanism necessitates a capacity to estimate changes throughout all forests within a country’s boundaries. Nation-wide monitoring is needed in particular to avoid displacement of deforestation within a country where reduced deforestation could occur in one portion of the country but increase in another portion [ ]. Appropriate methods need to be used by developing countries to demonstrate that they are fulfilling requirements in the framework of the REDD-plus mechanism. Monitoring systems at national levels in tropical countries can benefit from pan-tropical and regional observations and monitoring systems, by allowing countries to access to standard methods across regions and to ensure consistency between different national monitoring systems. Monitoring of forest resources at pan-tropical scale contributes also to the UNFCCC REDD-plus activities by monitoring potential international leakage effects and by providing global historical references.

Use of remote sensing technology to estimate deforestation at pan-tropical to regional scales

Estimating deforestation would be a major challenge without the use of satellite imagery, in particular for large and remote regions (Grainger, 2008). Satellite remote sensing combined with ground measurements play a key role in determining loss of forest cover. Technical capabilities and statistical tools have advanced since the early 1990s and operational forest monitoring systems at the national level are now a feasible goal for most developing countries in the tropics (Achard et al., 2010). However, reducing uncertainties in the land use change flux of the global carbon budget requires the capability to estimate changes throughout all forests of the tropical belt.

The principal monitoring requirement to support REDD-plus activities falls at the national level. Analyses that span the tropics can supplement these efforts by providing consistency and ensuring that major areas of deforestation are detected. Improved pan-tropical observations can support the activities which are starting in the framework of the REDD-plus readiness mechanism. While primary reporting would occur at national or sub-national levels, pan-tropical monitoring could contribute through 1) identifying critical areas of change, 2) helping to establish areas within countries that require detailed monitoring, and 3) ensuring consistency among national efforts. Main requirements of pan-tropical monitoring systems are that they measure changes throughout all forested area, use consistent methodologies at repeated intervals to obtain accurate results and verify the latter with fine resolution observations (GOFC-GOLD, 2010).

Some technical guidelines already exist: the IPCC guidance and guidelines for Land Use, Land-Use Change and Forestry (LULUCF) and the GOFC-GOLD REDD Sourcebook. The Good Practice Guidance for LULULUCF (IPCC, 2003) has been approved by developed countries (‘Annex-I’ countries) for Kyoto Protocol reporting and has been recommended to be used by developing countries (‘non Annex-I’ countries) for REDD-plus. Based on UNFCCC approved methodologies, the GOFC-GOLD REDD Sourcebook (2010) aims at providing additional explanation and methodologies to support readiness mechanisms for building national REDD-plus monitoring systems.

Many methods of satellite imagery analysis can produce adequate results from pan-tropical to national scales. From a methodological point of view, one of the key issues is that satellite data needs to be interpreted (digitally or visually) for forest cover change, i.e. focusing on the inter-dependent interpretation of multi-temporal imagery to detect and characterize changes. Two general remote sensing-based approaches are currently used for capturing deforestation trends at the pan-tropical to national level:

- **Analysis of wall-to-wall coverage from moderate spatial resolution imagery from optical or radar sensors** (20-30 m spatial resolution). An analysis that covers the full spatial extent of the forested areas with moderate spatial resolution imagery, termed “wall-to-wall” coverage, is ideal, but may not be practical over very large, heterogeneous areas and commensurate constraints on resources for analysis.

- **Statistical sampling designed to estimate deforestation from moderate spatial resolution imagery from optical sensors**. A sampling procedure that adequately represents deforestation events can capture deforestation trends. Because deforestation events are not randomly distributed in space, particular attention is needed to ensure that the statistical design is adequately sampled within areas of potential deforestation (e.g. in proximity to roads or other access networks), e.g. through a high density systematic sampling when resources are available (Mayaux et al., 2005).

The use of moderate resolution satellite imagery for historical assessment of deforestation has been boosted by the recent free availability of the Landsat Global Land Survey Database through the Earth Resources Observation Systems (EROS) Data Center (EDC) of the United States Geological Survey (http://glovis.usgs.gov). This database includes a nearly complete pan-tropical coverage of good quality, orthorectified and geodetically accurate data from the Landsat satellites, available at no cost for the epochs mid-1970s at 60 m × 60 m resolution(GLS-1975), and circa 1990 (GLS-1990), circa 2000 (GLS-2000) and mid-2000s (GLS-2005) at 28.5 m × 28.5 m resolution. These GLS datasets play a key role in establishing historical deforestation rates although in some parts of the tropics (e.g. Western Colombia, Central Africa and Borneo) persistent cloud cover is a major challenge to using these data. For these regions the GLS datasets can be complemented by remote sensing data from other satellite sensors with similar characteristics, in particular sensors in the optical domain with moderate spatial resolution (Table 1).

Table 7. Availability of moderate resolution (20m×20m - 50m×50m) optical sensors

Nation	Satellite / sensor	Resolution & coverage	Feature
U.S.	Landsat-5 TM	30 m × 30 m 180 km ×180 km	offers images every 16 days to direct receiving station
U.S.	Landsat-7 ETM+	30 m × 30 m c.60 km ×180 km	Since June 2003 data gaps outside of the central portion of images
U.S./Japan	Terra ASTER	15 m × 15 m 60 km × 60 km	Data is acquired on request and is not routinely collected for all areas
India	IRS-P6 LISS-III	23.5 m × 23.5 m 140 km ×140 km	India uses for their Forest Assessments
China/ Brazil	CBERS-2 HRCCD	20 m × 20 m 113 km swath	Brazil uses on-demand images to bolster their coverage.
UK (DMCii)	UK-DMC	32 m × 32 m 160 km ×660 km	Commercial; Full coverage of sub-Saharan Africa acquired in 2010.
France	SPOT-5 HRV	5×5m / 20×20m 60 km ×60 km	Commercial; Indonesia & Thailand use alongside Landsat data
Spain/UK	Deimos-1 and UK-DMC2	22 m × 22 m 640 km swath	Commercial (DMCii); new version of UK-DMC; Launched in 2009
Japan	ALOS AVNIR-2	10 m × 10 m 60 km × 60 km	Data is acquired on request and is not routinely collected for all areas

JRC collaboration with FAO Forest Resource Assessment

The FAO Forest Resources Assessment 2010 programme - FRA 2010 – is based on two complementary pillars: the national reporting and the Remote Sensing Survey (RSS) aiming at deriving forest cover change at global to continental scales. The JRC TREES project is deeply collaborating with FAO FRA 2010 RSS[2] and has taken profit of the technological improvements and better access to remote sensing data to expand the scope of the RSS compared with both FRA 1990 and FRA 2000 (Drigo et al., 2009):

(i) It has been extended to all lands (not just the pan-tropical zone),

(ii) The survey aims at estimating forest change for the periods 1990-2000-2005 based on a sample of moderate resolution satellite imagery,

(iii) Estimates of forest areas and change rates are statistically valid (i.e. accurate and precise) at global, continental and sub-regional levels,

(iv) The survey is based on a much higher number of smaller samples than the previous FRA exercises, sampled systematically: a 10 km × 10 km sample with 5 km buffer (i.e. size of 20 km × 20 km) are located at each intersection of the 1 × 1 degree lines of latitude and longitude that overlies land. These dimensions were chosen to allow spatially explicit monitoring at a scale relevant to land management.

This sampling scheme leads to c.13,500 sample units for the terrestrial part of the globe or c.9,000 sample units when excluding desert areas and represents circa 1% of the land surface (0.8% along the equator) with the geographical grid (Fig. 1). This approach is expected to deliver regionally accurate estimates of forest cover change, as well as national estimates for those countries where sampling intensity is sufficient. Testing of the systematic sampling design within Brazilian Amazon resulted in low standard error of less than 5% of forest cover change rate (Eva et al., 2010).

Time-series of moderate resolution remote-sensing data are attached to each sampling location (Fig. 2) through a quality-controlled, standardized and decentralized process (Beuchle et al., 2011). Several processing steps are successively conducted on the satellite datasets: (i) selection of the best data, (ii) eventual mosaicking of data, (iii) cloud detection and removal, (iv) radiometric calibration, (v) image segmentation, (vi) automatic labeling by a spectral library, (vii) visual check by JRC interpreters, (viii) validation by national experts (see below). The land cover legend includes a few land-cover classes: Tree cover, mosaics of trees and other land cover, Shrub cover, other Land Cover, water,

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[2] The FAO FRA 2010 RSS relies mainly on results provided by JRC over the tropics (TREES project - South and Central America, Sub-Saharan Africa and Southeast Asia), Europe (Forest Action) and Russian Siberia.

clouds & no data. A minimum mapping unit (MMU) of 5 hectares (or 50 pixels at 30m×30m resolution) is considered for the interpretation of the satellite imagery to identify the forest cover changes. A finer "detection unit level" at about 1 hectare is used in a first automated segmentation and labeling step before aggregation to 5–ha objects for the interpretation phase.

Being a main partner of FAO's FRA 2010 RSS (FAO/JRC/SDSU/UCL, 2009), JRC scientists collaborate with remote sensing and forestry experts from tropical countries in order to estimate forest cover changes at pan-tropical level. In this context, the JRC organised several workshops to train forestry experts on the remote sensing methods developed at JRC for the validation of the initial tree cover maps (Simonetti et al., 2010). JRC and FAO scientists collaborated with more than one hundred remote sensing and forestry experts from tropical countries, including largely forested ones like Brazil, India, Indonesia and Democratic Republic of Congo. An example is illustrated in the section dedicated to capacity-building activities of this report.

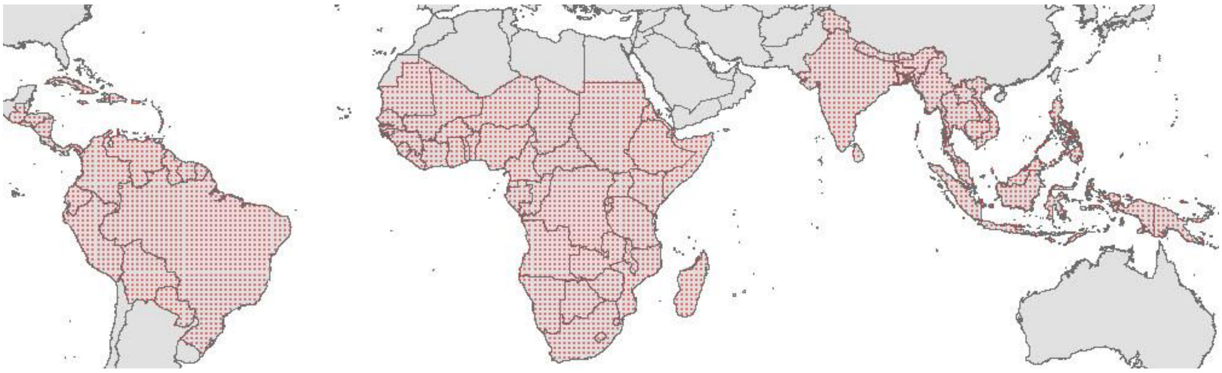

Figure 1. Systematic sampling scheme of the FAO Remote Sensing Survey / JRC TREES over the tropical regions.

Figure 2. Time series of Landsat imagery at 30 m × 30 m resolution (TM in 1990, ETM+ in 2001, TM in 2006) over a 20 km ×20 km size sample unit in Africa (Gemena region in Democratic Republic of Congo)

Pilot-studies in Central Africa and South America

The systematic sampling approach has been applied earlier in Central Africa to derive area estimates of forest cover change for the period 1990-2000 (Duveiller et al., 2008) using Landsat imagery. The approach was operationally applied to the entire Congo River basin to estimate deforestation regionally and nationally when applicable (with a sufficient number of samples). The survey was composed of 10 km × 10 km sampling sites systematically distributed every 0.5◦ latitude × 0.5◦ longitude over the whole forest domain of Central Africa, corresponding to a sampling rate of 3.3%. For each of the 571 sites, subsets were extracted from both Landsat TM and ETM+ imagery acquired in 1990 and 2000 respectively. The satellite imagery was analyzed with object-based (multi-date segmentation) unsupervised classification techniques. Around 60% of the 390 cloud-free images do not show any forest cover change. For the other 165 sites, a change matrix is derived for every sample site describing four land cover change processes, e.g. deforestation, reforestation, forest degradation and forest recovery. The exercise illustrates that the statistical precision depends on the sampling intensity. For a region like Central Africa (with 180 million ha), using 400 samples, the exercise estimates the deforestation annual rate at 0.21 % between 1990 and 2000 with a statistical confidence interval of ± 0.05%. The overall accuracy of the land cover classifications used for deriving forest change dynamics was assessed by an independent interpreter to 91%. A graphical representation is provided in Fig. 3.

The global systematic sampling scheme presented in previous section can be intensified to produce results at the national level. Deforestation estimates derived from two levels of sampling intensities have been compared to estimates derived from the official inventories for the Brazilian Amazon and for French Guiana (Eva et al., 2010). By extracting nine sample data sets from the official wall-to-wall deforestation map derived from satellite interpretations produced for the Brazilian Amazon for the year 2002 to 2003, the global systematic sampling scheme estimate gives 2.8 million ha of deforestation with a standard error of 0.1 million ha. This compares with the full population estimate from the wall-to-wall interpretations of 2.7 million ha deforested. The relative difference between the mean estimate from sampling approach and the full population estimate is 3.1% and the standard error represents 4.0% of the full population estimate. To intensify this global sampling to French Guiana Landsat-5 TM data were used for the historical reference period, 1990, and coverage of SPOT-HRV imagery at 20 m × 20 m resolution was used for year 2006. The estimates of deforestation between 1990 and 2006 from the intensified global sampling scheme over French Guiana are compared with those produced by the national authority to report on deforestation rates under the Kyoto protocol rules for its overseas department (Stach et al., 2010). The latter estimates come from a sampling scheme of nearly 17,000 plots derived from the traditional forest inventory methods carried out by IFN (Inventaire Forestier National) and analyzed from same spatial imagery acquired between year

1990 and year 2006. The intensified global sampling scheme leads to an estimate with a relative difference from the IFN of 5.4%. These results demonstrate that the intensification of the global sampling scheme can provide forest area change estimates close to those achieved by official forest inventories with precisions of less than 10 %, although only estimate errors from sampling have been considered and not errors from the use of surrogate data.

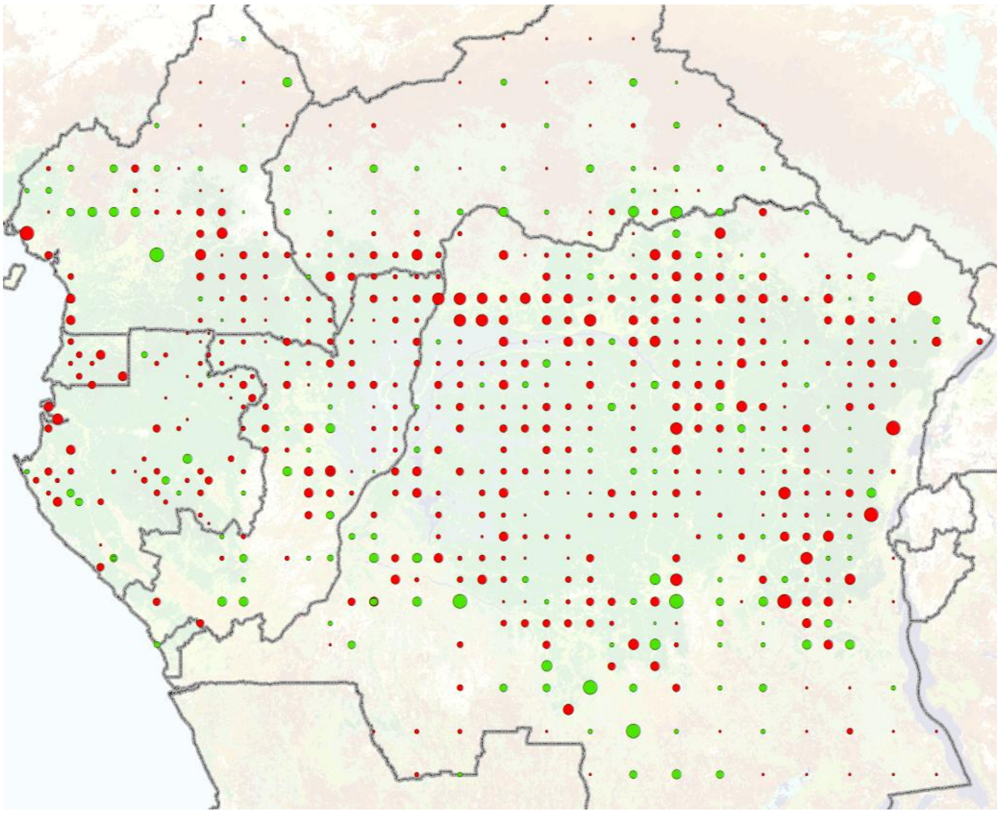

Figure 3. Map of Deforestation estimates in the Congo Basin between 1990 and 2000. Green circles correspond to reforestation areas, while red circles correspond to deforestation areas. The size of the pie charts is proportional to the deforestation intensity.

Analysis of wall-to-wall coverage from moderate spatial resolution radar imagery

Optical mid-resolution data have been the primary tool for deforestation monitoring. Other types of sensors, e.g. Synthetic Aperture Radar (SAR) - or Radar, are potentially useful and appropriate (a full list of current and future SAR sensors is available in the GOFC-GOLD REDD Sourcebook) .Radar remote sensors are active systems: it transmits short pulses of energy toward the surface below, which interact with surface features such as forest vegetation. Radar sensors operate in the microwave region (ca. 3-70 cm) which generally penetrate through atmospheric particulates (e.g., haze, smoke, and clouds), thus alleviating limitations of optical data in persistently cloudy parts of the tropics. Microwaves interact with forest canopies, with the amount of backscattered energy dependant in part on the three-dimensional structure and moisture content of the vegetation and underlying soils. SAR backscatter is correlated to forest biomass for low values of biomass with saturation for high values (Le Toan et al., 2004). Longer wavelengths (e.g. P-/L-band) penetrate deeper into forest canopies than shorter wavelengths (e.g. C-/X-band). As a consequence, the saturation in the relationship between backscattered signal and biomass occurs at higher values for longer wavelengths, i.e. at approximately 30 T/ha for C-band, 50 T/ha for L-band and 150-200 T/ha for P-band.

Imagery from radar sensors have been demonstrated to be usable for tropical forest cover monitoring at local scales, although no operational tropical forest monitoring has been yet developed for large areas (region or continent). This is mainly due to three reasons: (i) lack of technical expertise and resources to process and analyze radar imagery, (ii) lack of consistent regional and pan-tropical coverage of SAR data until recently, (iii) technical limitations of SAR data for the assessment of deforestation. Indeed in some cases deforested areas are confused with forest areas in SAR imagery, in particular when the deforestation event is very recent with presence of tree debris on the ground, or when dense secondary vegetation has already regrown. This highlights the need of time-series of satellite radar imagery with high temporal frequency (at least once a year) to increase the efficiency of detection of deforestation events. Strategies are therefore needed to ensure regular and systematic acquisition of SAR data coverages over large regions. So far, only the Japanese Aerospace Exploration Agency (JAXA) has designed such a dedicated observation strategy for the PALSAR (Phased Array L-band Synthetic Aperture Radar) sensor on board the Advanced Land Observing Satellite (ALOS), launched in January 2006 which ended its operation in April 2011. JAXA acquisition strategy for this sensor consists in a systematic imagery acquisition over all Earth’s land masses in a wall-to-wall manner at 10 m × 10 m to 100 m × 100 m resolution at least twice per year. Thanks to this observation strategy, consistent datasets are being used for the early detection of deforestation or for regional tropical forest mapping (Hoekman et al., 2011). Wall-to-wall mosaics of pan-tropical regions have been produced in the frame of the ALOS Kyoto and Carbon Initiative (e.g. De Grandi et al., 2011 for Africa by JRC), and will be compared with the tropical mosaics generated by the SAR sensor of the Japanese Earth Resources Satellite (JERS-1) in the mid-1990s. The ALOS mosaics are also expected to complement or replace optical-based remote sensing surveys for regions where little or no cloud-free data is available, as illustrated in Fig. 4.

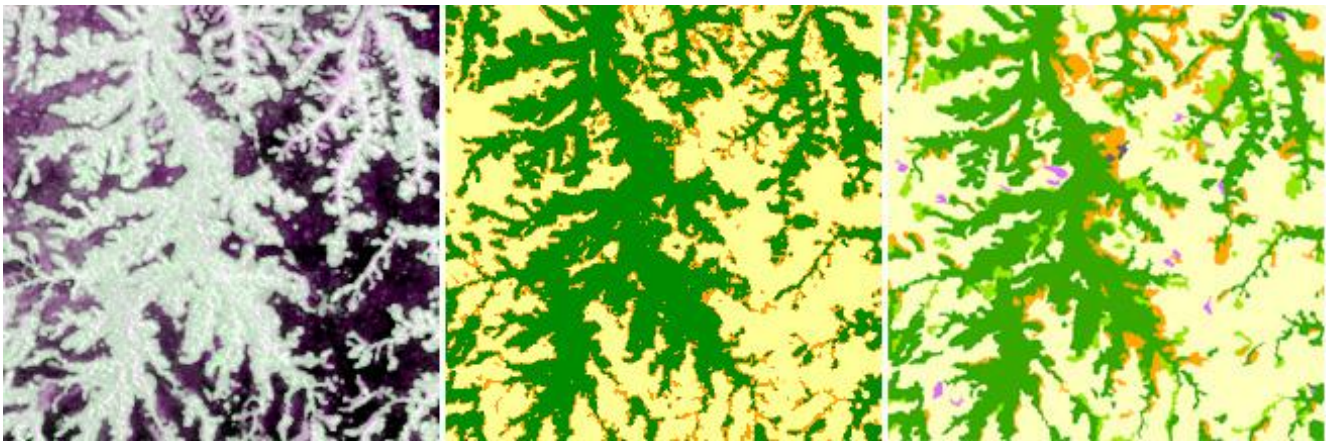

Figure 4. Comparison of result of land cover maps from ALOS-PALSAR and Landsat-ETM+ imagery over a 20 km ×20 km size box in Congo Basin (Centered at 3˚ South / 18˚ East). Left panel: PALSAR image at c. 50 m × 50 m resolution of year 2007 (HH / HV channels); center panel: classification from ALOS-PALSAR; right panel: classification of Landsat ETM+ imagery at 30 m × 30 m resolution of year 2000 (green: forest vert, orange : shrub, yellow: other land cover)

Use of fine spatial resolution imagery

A new challenge is to provide a consistent coverage of fine resolution satellite imagery for global forest cover monitoring, i.e. at least a statistical sample or, more challenging, a wall to wall coverage. The finer resolution (from 1m × 1m up to 10m× 10m) will allow to derive more precise forest area estimates and canopy cover assessment, and therefore more reliable statistical information on forest area changes, in particular for estimating forest degradation and forest regrowth, and their related carbon emissions or removals.

To continue and complement the JRC's TREES forest cover assessment covering the period 1990-2005, the European Space Agency (ESA) has launched a joint action with the JRC to produce better estimates of forests cover changes in the tropical forests of Latin America and South East Asia up to the year 2010 from fine spatial resolution satellite imagery. Assessments for year 2010 are essential for building updated deforestation reference rates at global to regional levels. ESA will create a harmonized remote sensing ortho-rectified imagery geo-database which will cover sample units of 20km × 20km size located at the degree confluence for the year 2010. This imagery geo-database is based on satellite data acquisitions performed during the period mid 2009 – beginning 2011 from a series of satellite sensors with fine spatial resolution: AVNIR-2 sensor onboard the ALOS platform complemented by sensor onboard DEIMOS-1 platform for each of the each 1º×1º geographical latitude/longitude intersection. This dataset will be used to assess the state of the tropical forest cover forest changes for the period 1990 – 2010 and is expected to constitute a benchmark dataset for accurate assessment of forest degradation and forest regrowth at continental level.

In the perspective of forest monitoring with higher level of details, it is important to note that the first satellite of the Sentinel-2 system, funded under a joint programme of the ESA and the European Commission, is planned to be launched in 2013 (Martimort et al., 2007). The Sentinel-2 satellite will carry onboard an optical Earth observation multispectral optical sensor with 10 m ×10 m spatial resolution and swath of 290 km. With an orbiting revisit time of 10 days for one satellite and five days when a pair of satellites will be operational, the Sentinel-2 system will include a systematic acquisition plan of satellite imagery over all terrestrial land areas of the world. The envisaged data policy will allow full and open access to Sentinel-2 data, aiming for maximum availability of Earth observation data in support to the implementation of environmental and climate change policies.

Future perspectives

There are strong incentives to reduce uncertainty in the estimation of carbon fluxes arising from deforestation by using better data on forest above-ground biomass or carbon stocks in combination with more accurate satellite-derived estimates of deforestation.

In the framework of the to the UNFCCC REDD-plus activities the extension of the analysis of tropical deforestation to degradation and forest regrowth will be a crucial requirement.

Dedicated tools for monitoring forest cover need to be improved through the use of the most recent satellite image technology, including radar and optical imagery at finer spatial resolution (10m ×10 m or finer), with a higher temporal frequency (at least yearly). The on-going methodological efforts are expected to narrow the gaps between the demand of more accurate estimation of global carbon budget and the limitations of currently available remote sensing data.

International coordination needs to be further developed between space agencies and implementing institutions (e.g. through the Committee on Earth Observation Satellites – CEOS - or the Group on Earth Observations - GEO) to ensure repeated coverage of the world's forests with different type of data and easy access to adequate quality data at reasonable to no cost.

Effective technology transfer on forest monitoring using remote sensing to local institutions throughout the tropics needs to be developed and sustained in a very near future.

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CONCLUSIONS AND RECOMMENDATIONS FOR THE JRC WORK PROGRAM

Recommendations for the agriculture sector

D. Radcliffe[1]

Until recently, agriculture has been comparatively neglected in the discussions on mitigation of greenhouse gas emissions. The balanced perspective of this meeting has helped to put agriculture on an equal footing to forestry in considering carbon stocks and fluxes in the landscape.

DEVCO is particularly interested in how positive development outcomes can be achieved as co-benefits of action to combat climate change. It is helpful to adopt a clear development rationale for mitigation. On the one hand this recognises that net reduction of greenhouse gases is a global public good, with positive impacts on future climate trends. Another aspect is understanding the synergies and trade-offs between actions taken to reduce GHG emissions and those that contribute to adaptation or improved livelihoods. For example, increased soil carbon traps CO_2 that would otherwise have been emitted, but also improves soil resistance to erosion and water holding capacity, sustaining crop yields. It therefore follows that measures to sequester carbon in soils can have co-benefits for adaptation to climate change and for improved food security or income generated through better crop yields. This is a general picture, and the magnitude of these benefits will be highly site specific, dependent on soil type and climate. Soils are complex systems and in some cases an increased ratio of carbon to nitrogen may have some negative crop yield impacts.

As with REDD+, incentives need to be considered to encourage avoided emissions and sequestration of carbon through changes in land use or agricultural practice. Any system of incentives and rewards needs to be underpinned by a rigorous MRV system. The challenges of putting effective MRV systems in place for terrestrial carbon monitoring have been discussed at this workshop. Monitoring carbon in soils is even more challenging than monitoring carbon in forests but there is valuable experience to draw on. We recognise that most of the mitigation potential through agriculture and land use change is in developing countries and that these countries, and their farmers, have most to gain from mitigation incentives. However, MRV methods need to be cost effective and easy to apply so that they can be used in developing countries where accurate information, and capacity, may be constrained. In these circumstances attention needs to be given to the use of proxies and modelling, verified by a reasonable density of ground observations and backed up by remote sensing.

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Creating an incentive structure to reward mitigation or carbon sequestration is open to risks of capture by elites, or may exacerbate the already growing problem on land grabbing in Africa or other developing regions. Smallholder farmers in developing countries are already among the poorest. Incentives for better land husbandry to conserve carbon stocks could augment income streams, or could be channelled through governments to support rural development programmes. There are arguments for and against a market based mechanism, a public subsidy or a combination of these mechanisms. It was noted that the Clean Development Mechanism of the UNFCCC does not consider carbon sequestration in soils and that its MRV requirements would not be cost effective when applied to large numbers of small farmers. Public funding could be linked to NAMAs (Nationally Appropriate Mitigation Actions), noting that more than half of the African countries that have submitted NAMAs in response to the Copenhagen Accord, have included agriculture as a sector of focus.

GHG mitigation can also be regarded as an environmental service. There may be potential for clustering environmental benefits (e.g. with soil conservation, biodiversity conservation, etc.) in a PES (payment for environmental services) model.

Clearly JRC can play a key role in developing and testing MRV methodologies in agricultural systems. It is important to combine efforts with other researchers and practitioners in the field, including FAO and others, to build on ongoing work and address gaps. Recognising the data gaps in many developing countries it is important to collate data from diverse sources, including the 'grey literature' of consultants' reports as well as peer reviewed science. JRC needs to keep in mind the development-relevance of research products and their ease of application in developing countries.

To maximise the usefulness and applicability of MRV in agricultural systems it is important to bridge the gaps between MRV, policy and action. JRC needs to continue working closely with DEVCO to ensure the linkages are made with EU policy and with development programmes in the field.

Recommendations for the forestry sector

M. Bousquet[1]

Monitoring, Reporting and Verification (MRV) systems have received particular attention in the recent debate on REDD+, as a key element for ensuring that payments for avoided deforestation are an effective, equitable and sustainable incentive mechanism. This has generated a new "market" for research institutes and consulting companies, innovative technical solutions being proposed, with associated costs, coverage and claimed accuracies, which vary significantly from one option to the other. Policy-makers often do not have the expertise needed to assess the feasibility, reliability and cost-efficiency of proposed options, and there is a need for organisations such as the Joint Research Centre to provide this independent scientific and technical analysis, as part of their support to knowledge-based policy-making. JRC can play a very positive role as neutral broker between policy makers, and proponents of scientific and technical options/methods, as this was the case in this conference.

Forests play different roles and have different functions. There are multiple policy goals associated to the forestry sector, and a huge variety of monitoring systems has been proposed each of them trying to contribute to different policy objectives (depending on the choice of policy objective, it is proposed to monitor for example carbon, governance, illegal logging, deforestation, access and benefit sharing, biodiversity and protection of forests, ecosystems services,…), some of the MRV systems being framed as part of a specific process (FCPF – Forest Carbon partnership Facility, UNREDD, FLEGT Forest law enforcement Governance and Trade VPA Voluntary partnership agreements …).

Comparability and coherence of monitoring systems, as well as their cost-effectiveness and value for money, need to be analysed and evaluated, both at strategic and operational levels. The timeframe of the monitoring frameworks also deserve attention of policy-makers and experts. Experience from countries/regions such as Brazil or the European Union may be helpful in that regard.

As those MRV systems aim at feeding policy-makers with relevant information, it is crucial to place partner countries in the driving seat, both for policy definition and implementation, and for policy evaluation, to which MRV systems will contribute. MRV options need to be developed with partner countries to feed their policy making process, at a reasonable and affordable price.

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One of the objectives of MRV systems is to give confidence to public and private donors, whatever the form of payments for avoided deforestation. Indeed policy-makers, the general public and taxpayers need to be reassured that the systems in place really contribute to climate change mitigation and adaptation objectives as well as development objectives, both at international level and at national and sub-national level.

Access to reliable information from all sorts of stakeholders and transparency of MRV related data and information will be essential in that context. Stakeholders need to be involved in the oversight of the MRV systems put in place for REDD+. Experiences of oversight from stakeholders on the Legality Assurance Systems developped in the framework of FLEGT VPAs can be useful in that context. Access to information is important but will not be enough. Experience of the *Observatoire des forêts d'Afrique centrale* is a good example. Going beyond the production of fair and reliable information a sector, there is a need to build capacity at national and regional level in developing countries of civil society and stakeholders to analyse MRV related data and information, so as to keep governments accountable for their policy-making and the implementation of these policies.

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Abstract

Improved terrestrial carbon management offers tremendous potential for climate change mitigation and, in many cases, there are associated co-benefits such as increased productivity, resilience, and biodiversity. It is expected that governments will agree to incentives for improved management of some forms of terrestrial carbon in developing countries, including maintaining existing carbon and creating new carbon in agriculture, forestry and other land-uses. Across a wide range of geographic scales and land classes, there is a need for a coherent, integrated information base for effective land management practices that produce real increases in sequestration together with real reductions in greenhouse gas (GHG) emissions from terrestrial sources, and transparent, consistent, and comparable quantification of changes in carbon stocks.

In January 2011, the Institute for Environment and Sustainability of the Joint Research Centre organized an inter-service meeting on “Monitoring, Reporting and Verification systems for carbon in soils and vegetation in African, Caribbean and Pacific countries” with the objective of refining its long-term research agenda in that domain. This was achieved in the light of the needs of the Directorates-General involved in the development and environment policies namely DEVCO, ENV, CLIMA, ENTR, RTD and AGRI as well as of the recent evolution of the UNFCCC negotiations.

This report encompasses the proceedings of the meeting together with the conclusions and recommendations to JRC work program stated by the invited experts and policy-makers from the different relevant DGs. The presentations given during the meeting and the final report are also available on the ACP Observatory website (http://acpobservatory.jrc.ec.europa.eu/redd.php).

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

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