SmartSOIL

Sustainable farm Management Aimed at Reducing Threats to SOILs under climate change

European Commission

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289694.

Introduction

Enhancing soil carbon through agricultural management provides an important opportunity to address challenges of climate change, soil degradation and for improving the fertility of soil to sustain the growing demand for food.

The importance of soil carbon

Soil organic carbon (SOC), a component of organic matter, is vital to essential soil functions and to the ecosystem services that soils deliver which include food production, water storage and filtration, carbon storage, nutrient supply to plants, habitat and biodiversity. Some of these functions are not only affected by soil carbon stocks, but also by the flows of carbon through management of inputs from crops, residues and manures. Maintaining and increasing SOC content therefore results in multiple benefits. In doing this it provides an opportunity to meet increasing resource demands that arise from the intense pressures of land use and climate change.

Farming practices that lead to declining returns and inputs of carbon to soils pose a threat to soil functions by reducing availability of organic matter for soil microbes and by affecting soil structure, and soil C stocks that are key to regulating greenhouse gas emissions. Depletion of SOC is exacerbated through agricultural practices with low returns of organic material and through practices that favour soil organic matter decomposition and erosion.

A number of agricultural management practices have shown potential for increasing SOC content. They can prevent or reverse the loss of soil carbon as well as confer some resilience to soils under intensification pressures. Many of the practices that promote carbon accumulation can contribute to improving long-term crop productivity, since increased SOC stocks improve the physical and biological properties of the soil; and potentially the profitability of farming systems.

Changes in SOC stocks significantly influence the atmospheric carbon dioxide (CO_2) concentration. Agricultural practices that increase SOC content therefore have potential for climate change mitigation, though it should be noted that changes in soil carbon stocks (either losses or gains) decline over time as stocks approach a new equilibrium value.

Project overview

SmartSOIL developed an interdisciplinary approach, combining scientific insights and understanding of the farming socio-economic context, to identify management practices that can optimise soil carbon storage and crop productivity.

SmartSOIL objectives

The aim of SmartSOIL was to contribute to reversing the current degradation trend of European agricultural soils by improving soil carbon management in European arable and mixed farming systems covering intensive to low-input and organic farming systems. This entailed two overall aims:

- To identify farming systems and agronomic practices that result in an optimized balance between crop productivity, restoration and maintenance of vital soil functions (fertility, biodiversity, water, nutrient cycling and other soil ecosystem services) and soil carbon sequestration and storage.
- To develop and deliver a decision support tool and guidelines to support novel approaches, techniques, and technologies adapted to different European soils and categories of beneficiaries (farmers, farm advisory and extension services, and policy makers).

Meta-analyses of data from European long-term experiments were used to model the impact of different farming practices on SOC in arable and mixed farming systems. Based on this modelling, and on an extensive stakeholder consultation process in six case study regions (Denmark, Scotland, Spain, Poland, Italy and Hungary), a Toolbox was developed to support farmer and policy maker decision making. The impacts of the different practices on the economics of farm businesses, and the barriers and incentives associated with implementing them, were also investigated at case study level.

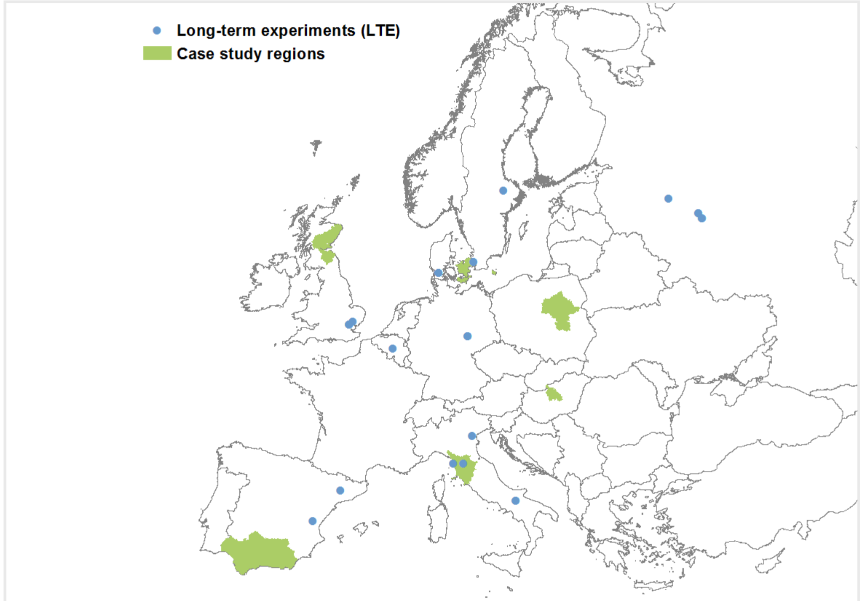


Figure 1: Location of LTEs and case study regions

Improved scientific understanding

Optimising crop productivity and soil carbon stocks

It has been known for some time that healthy soils provide a sound platform for crop production. Healthy levels of soil organic matter improve the workability of soils, improve their ability to retain and store water (so that they are less susceptible to drought), and can increase nutrient supply, which is more important in low input systems than those that already receive high levels of fertilization. For this reason, soil management is critically important for producing high quality crops at yields that deliver good economic returns for farmers. SmartSOIL investigated the links between crop productivity and flows and stocks of soil carbon.

Soil and crop management has significant effects on soil carbon stocks and flows and hence on soil functions and the ecosystem services that soils supply. SmartSOIL, working on arable and mixed farming systems in Europe, developed an innovative approach using the soil carbon flow and stocks concept (Fig. 2) to explore how management of soil carbon affects crop productivity, SOC stocks and other ecosystem services.

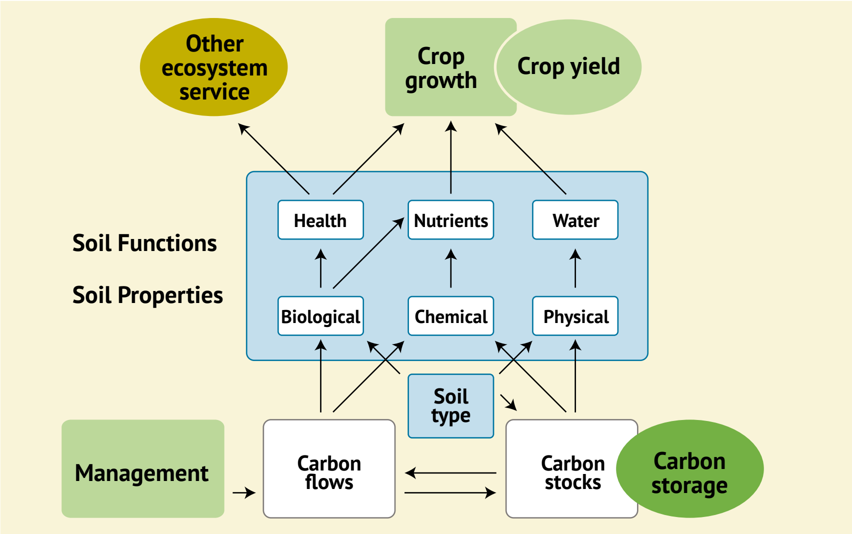


Figure 2 Inter-linkages between soil management, carbon flows and stocks, and crop yield

Predicting the effects of crop management on soil carbon and on yield

SmartSOIL developed a simplified model that aims at predicting the effects of soil and crop management on 1) soil carbon stocks, and 2) crop productivity. It combines a model of long-term soil carbon dynamics in the topsoil and subsoil with a model of yield response to nitrogen supply from soil, manure and fertiliser. The effects of crop yield are translated into a nitrogen fertiliser response curve. The model thus aims to predict the effects of crop management on developments in soil carbon and resulting effects on crop yield potential and response to nitrogen fertilisation. The model also considers the effects of soil management on the vertical profile of carbon in soils and how this affects soil functions and crop productivity.

Identification of key principles and practices to enhance soil carbon

Principles of soil organic carbon management

- Soil organic carbon is sustained through sufficient inputs of organic matter from roots, crop residues, manure and compost to (out)balance losses from decomposition of soil organic matter.
- Soil organic matter contributes to sustaining soil productivity by enhancing soil water retention and nutrient supply. Also, soil organic carbon enhances soil structure and workability of high clay content soils.
- Inputs of organic matter to the soil contributes to sustaining soil biodiversity, which also influences pests and diseases (positively and negatively) requiring management targeted to local conditions.
- Preservation of current soil carbon stocks as well as enhancing these plays an important role for contributing to climate change mitigation. However, potential trade-offs with increased emissions of non-CO_2 greenhouse gases (methane and nitrous oxide) as well as saturation of the carbon storage potential over time have to be considered.
- Effective management of soil organic carbon requires a long-term effort, has implications that extend beyond each farm, and this commitment is more effective if it is a key element in strategic farm management.
- Soil carbon management depends on current soil carbon levels. On soils with acceptable or good soil carbon, the aim is to maintain these levels of soil carbon, whereas effective action needs to be taken on soils with low carbon to enhance contents. Measures in both cases involve adapted crop rotations, residue retention, manure application and cover crops. Such actions can be combined with no-tillage practices to further enhance soil carbon and improve soil structure in near-surface soil layers.
- Soil organic carbon management also involves management of nitrogen and phosphorus, and soil carbon management needs to be seen in the context of farm-scale nutrient management. The full benefits of enhanced soil organic matter levels on crop yield are only fully captured if the actions undertaken to enhance soil organic matter are timed well to provide the water and nutrients (in particular nitrogen) that the crop needs, if soil carbon management is aligned with appropriate management to prevent and control weeds, pests and diseases. This requires adaptation of the management actions to local soil and climatic conditions as well as to (region) specific farming systems.

Practices that enhance soil organic carbon

In general, SOC stocks can be increased in three main ways:

- by enhancing plant residues and root inputs to soils;
- increasing the quantity of organic matter inputs such as manure and compost to the soil (from on farm or off farm sources); and
- by reducing decomposition losses through minimising disturbance of soil.

We have shown in SmartSOIL that managing soils well, using appropriate combinations of the practices listed below, helps to improve resilience and to improve crop productivity.

Crop rotations

Improved crop rotations in which carbon inputs are increased over a rotation involves growing crops with long growing seasons, in particular when combined with legumes to improve the quality of soil organic matter inputs. Tailored crop rotation regimes, which build soil organic matter and soil carbon, can improve and maintain soil quality and fertility over the short and long term.

Residue management

Crop residues are materials left in a field or orchard after the crop has been harvested. They include stalks, stubble, leaves, roots and seed pods. Retention of crop residues, incorporated into the soil or left on the surface, can enhance soil organic matter and SOC storage, improving soil structure, root system development and plant growth, soil moisture retention, enhanced nutrient cycling, and decreased soil loss.

Adding manure or compost

Adding manure and compost is efficient for improving soil carbon since the added organic matter is more slowly decomposed compared to fresh plant residues. Also adding manure and compost will often reduce the need for mineral fertilisers. Improvements in soil quality due to manure or compost application have been shown to boost soil productivity and stimulate crop growth rates, resulting in potential yield improvements.

Cover crops/catch crops

Cover/catch crops during fallow periods provide year-round carbon inputs, not only from above-ground inputs, but also from root carbon. Adding cover/catch crops to crop rotations can help to improve soil quality, reduce soil erosion, retain nutrients, enhance nutrient cycling and water holding capacity, and as a result, potentially increase crop yields.

Conservation agriculture

Conservation agriculture is characterised by continuous minimum soil disturbance (minimum tillage); permanent organic soil cover (crop residues, mulches and cover crops); and diversification of crops grown (crop rotations). Minimum tillage can increase SOC in the upper layers of the soil; the effect is a function of working depth, intensity of cultivation, and extent of soil inversion. Once established, conservation agriculture can reduce the need for fertiliser and pesticide inputs, whilst stabilising yields.

FactSheets are available in the SmartSOIL Toolbox for each of these practices.

Opportunities for the farm business

SmartSOIL has investigated the impacts of the practices listed above on the economics of farms in six case study regions in Europe (Denmark, Scotland, Spain, Poland, Italy and Hungary). This cost-effectiveness analysis showed that there is potential for the uptake of SOC measures that can produce benefits to farmers in terms of improved farm gross margins. More detailed economic modelling of the adoption of measures over periods of up to 20 years in three case study regions (Scotland, Spain and Italy) reinforced the results of the cost-effectiveness analysis. In comparison to current practices: reduced tillage was favoured in Scotland, whereas a broader range of measures including tillage management, fertiliser management, crop rotations were favoured in Spain; no-till seeding and cover crops were found to be beneficial in Italy.

In general the benefits of adopting these measures can include improvements in yield or reductions in costs. In particular we have observed reductions in the need for mineral fertilisers due to more efficient use of nutrients from manures and crop residues. Significant reductions in fuel use have also been found due to reduced inputs and less fuel intensive tillage (in reduced tillage or no-till systems). The improved organic matter content of soils has also improved their workability. Adoption of measures can incur investment costs particularly where changes to tillage practices requires new machinery. Practices can be cost effective even where modest reductions in yield occur because of the potential to reduce inputs costs.

Our analyses, based on both existing literature and our case studies, have in some cases revealed a more nuanced picture of the benefits of soil management. In some situations yields decline and some input costs such as for crop protection have increased. Residue management has a high potential for SOC increase in most case study regions but this could only be achieved at a loss of gross margin due to foregone revenue from selling straw as a by-product. These findings reflect the fact that soil management choices need to consider the conditions of each farm and types of crops being grown. For example crop disease issues can be addressed by altering rotations which in themselves can improve soil organic matter levels. This also reflects the fact that adopting new practices is a medium to long term commitment where benefits will increase over time.

Overall the farmers we have spoken to have found positive benefits from adopting the different management measures. They have identified improvements in their soils including better structure, more earthworms, better drainage and improved water holding capacity. These improvements are appreciated in the context of increasingly uncertain weather patterns where healthier soil offers greater resilience. Higher organic matter contents have allowed access to soil for cultivation which would otherwise have been too fragile or water logged.

Healthier soils also provide benefits beyond the farm gate in terms of improved water quality, natural flood management, carbon storage and biodiversity. These benefits offer opportunities to obtain advice and rural development funding.

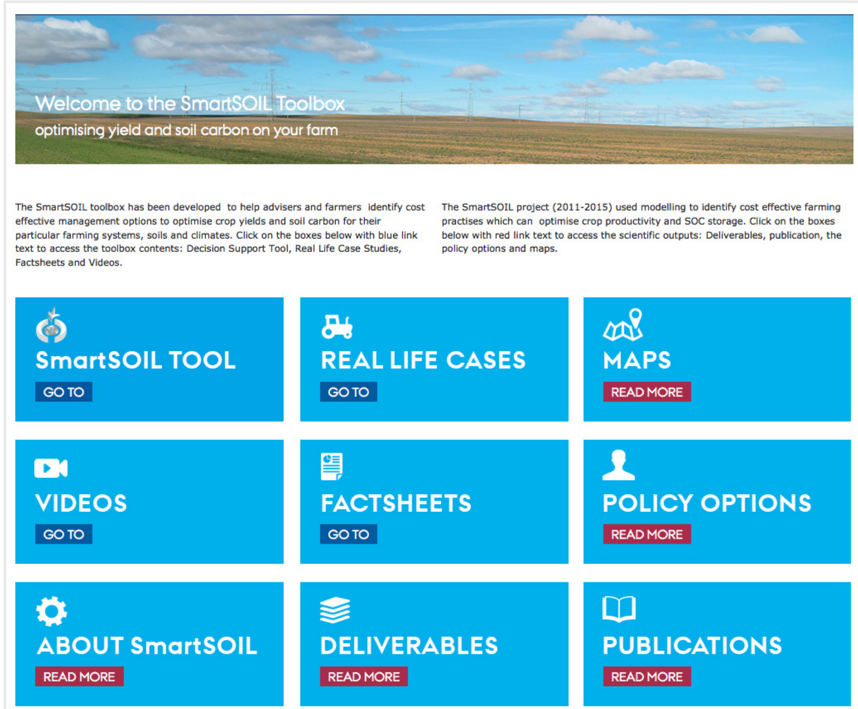
Bjarne Hansen runs a 279ha mixed farm in Sjælland, Denmark. He has incorporated minimum tillage and residue management into his crop rotations in order to improve soil structure and fertility across the whole farm. This has reduced his costs by some 36% and increased the farm gross margin by 2688 DKK (€360).

Bjarne says *"I spend 1534 dkk (€205) per hectare less than other farmers in the vicinity. The fuel cost saving was very evident because of reduced number of hours required for machinery use. Less nitrogen fertilizer is required due to higher nutrient use efficiency in the fields where the measure is applied".*

Main outputs – the Toolbox and how it can help with smarter decision making

The Toolbox, developed through an extensive stakeholder consultation process in the six case study regions, contains a set of different tools which present the project results and recommendations in formats appropriate to different users. The objective of the Toolbox is to increase the understanding of the linkage between soil management practices and soil productivity as well as soil carbon. Based on these findings, it also aims to outline potential options to influence better soil management at farm and policy level.

Elements of the Toolbox include: Real-Life Cases from selected farmers in six different European countries; videos demonstrating the application of different management practices at farm level; FactSheets summarising benefits, costs and experiences associated with the different management practices; and the SmartSOIL Tool. All of these tools were developed in order to help advisers and farmers identify cost effective management options to enhance crop yields and soil carbon for their particular farming systems, soils and climates. The tools are available in several EU languages and can be accessed via: **http://smartsoil.eu/smartsoil-toolbox/about**.



In addition, maps for policy makers and scientists are included which indicate inter alia soil potential stability, areas at risk of losing SOC, and current carbon stocks in the EU. Policy options to promote beneficial management practices at national and EU level are also an important component of the Toolbox for policy makers.

One key outcome mentioned in the list above is the SmartSOIL Tool; this Decision Support Tool has been developed in an iterative process involving several rounds of feedback and testing with the key stakeholders in the case study regions. Building on the SmartSOIL Simple Model (a combination of a carbon model, C-Tool, and a crop yield model) as well as EU-wide and region-specific datasets, this tool was developed to allow farmers and advisers across the EU to explore the effects of changing management practices on soil carbon, crop productivity and economic outcomes. By selecting a specific EU region the user will be able to choose from different management and cropping scenarios which are relevant to that region. Potential changes in yield and SOC content which can result from implementing the different practices are shown in the SmartSOIL Tool as detailed graphs annotated with explanations. In addition, information on benefits and costs for the different management practices is provided, helping the user to make informed decisions about more sustainable and cost-efficient soil management practices.

The tool is directly accessible via **smartsoil.eu/tool** and available in English, Danish, German, Spanish, Italian, Hungarian and Polish.

Opportunities for policy

Drawing on the SmartSOIL scientific results as well as extensive stakeholder involvement, six recommendations have been developed for how policy can better support improved soil organic carbon management in the EU.

1. Increase awareness of the role of soil organic carbon in delivering soil quality and soil fertility (and multiple ecosystem services) among policy makers in policy
2. Support pilot projects and provide incentives to farmers for implementing monitoring schemes/bookkeeping at farm level to monitor their carbon budgets (e.g. through Rural Development Programmes, European Innovation Partnership initiatives)
3. Increase the baseline and mandatory requirements for farmers related to soil quality in the Common Agricultural Policy
4. Improve Rural Development Programmes so that they address soil quality management in a more coherent and targeted manner, including possible targets and benchmarking for soil protection objectives (in addition to targets related to biodiversity, water, climate change, resource efficiency, and air quality)
5. Improve the participation of land managers (farmers) and other soil stakeholders in the process of designing and implementing Rural Development Programmes
6. Increase learning amongst farmers and advisers through: a) cooperation and demonstration opportunities to problem-solve around soil quality management, and b) training and demonstration to enhance awareness and understanding of the importance and benefits of soil organic carbon

Selected further reading

Selected Key Deliverable Reports

D1.3 Simplified model of managementon SOC flows and stocks and crop yield

D2.1 Report describing the practices and measures in European farming systems to manage soil organic matter

D3.2 Cost-effectiveness of SOC measures

D4.1 Overview and assessment report of decision support tools and knowledge platforms, SmartSOIL Report

D5.2 Overview of socio-economic influences on crop and soil management systems

All deliverables can be accessed via:
http://smartsoil.eu/smartsoil-toolbox/project-deliverables/

Key scientific papers

Relationship between C:N/C:O Stoichiometry and Ecosystem Services in Managed Production Systems. Bhim B. Ghaley, Harpinder S. Sandhu & John R. Porter. PLOS ONE April 20, 2015.

Do soil organic carbon levels affect potential yields and nitrogen use efficiency? An analysis of winter wheat and spring barley field trials. Myles Oelofse, Bo Markussen, Leif Knudsen, Kirsten Schelde, Jørgen E. Olesen, Lars Stoumann Jensen & Sander Bruun. European Journal of. Agronomy 66, 62–73, 2015.

Managing soil organic carbon: a farm perspective. Ingram, J., Mills, J., Frelih-Larsen, A., Davis, M., Merante, P., Ringrose, S., Molnar, A., Sánchez, B., Ghaley, B. B., Karaczun, Z. Published in : EuroChoices 13, 12–19, 2014.

Towards mitigation of greenhouse gases by small changes in farming practices: understanding local barriers in Spain. Sánchez B, Álvaro-Fuentes J, Cunningham R, Iglesias A. Mitigation and Adaptation Strategies for Global Change, 1–34, 2014.

Temperatures and the growth and development of maize and rice: a review. Sánchez B, Rasmussen A, Porter JR. Published in: Global Change Biology, 20(2), 408–417, 2014.

Enabling food security by verifying agricultural carbon. H. Kahiluoto, P. Smith, D. Moran and J. E. Olesen. Nature Climate Change 4, 309–310, 2014.

C-TOOL: A simple model for simulating whole-profile carbon storage in temperate agricultural soils. Arezoo Taghizadeh-Toosi, Bent T. Christensen, Nicholas J. Hutchings, Jonas Vejlin,Thomas Kätterer, Margaret Glendining, Jørgen E. Olesen. Ecological Modelling 292, 11–25, 2014.

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Estimating the Costs and Benefits of Adapting Agriculture to Climate Change. Anita Wreford, Dominic Moran, Andrew Moxey, K. Andy Evans, Naomi Fox, Klaus Glenk, Mike Hutchings, Davy I. McCracken, Alistair McVittie, Malcolm Mitchell, Cairistiona F. E. Topp and Eileen Wall. EuroChoices 14(2), 16–23, 2015.

The economics of soil C sequestration and agricultural emissions abatement. Alexander P, K. Paustian, P. Smith, and D. Moran. SOIL 1, 331–339, 2015.

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Imprint

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Project Sustainable management of agricultural soils in Europe for enhancing food and feed production and contributing to climate change mitigation (SmartSOIL)

Website smartsoil.eu

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 289694.

September 2015

Images sources
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