SmartSOIL

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

SEVENTH FRAMEWORK PROGRAMME

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SmartSOIL Final report

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1 Executive summary

The aim of the SmartSOIL project is to contribute to reversing the current degradation trend of European agricultural soils by improving soil carbon management. The project outputs aim to provide an important contribution to the understanding and management of soil carbon in the EU. Soil carbon management is an important tool in maintaining high crop productivity while sustaining and maintaining and increasing ecosystem service, such as water filtering and cleaning, nutrient cycling, biodiversity, and carbon sequestration to help mitigate climate change. There are, however, a number of soil carbon management strategies, and it is important to identify and quantify the effect of each measure in order to recommend the most appropriate strategy to maximise the effect of the measures, both in terms of yield and ecosystem service. In addition to the effect of soil carbon management measures on yield and ecosystem services it is necessary to analyse the cost-effectiveness of such measures, and to identify barriers to and incentives for farmers to apply such measures.

SmartSOIL used data from a range of long-term agricultural experiments to identify and quantify the effects of different soil carbon management measures. The long term experiments were located in different regions of Europe and thus represent different climatic regions and different approaches to farming, both at farm scale and policy levels. SmartSOIL identified, studied, and evaluated the effect on soil carbon and yield of measures such as minimum and zero tillage, application of animal manure, residue incorporation, cover and/or catch crops, fertiliser input and conservation agriculture practices. To each of these measures a cost-effectiveness analysis was carried out in order to evaluate cost and possible trade-off for farmers when applying the measures. Not all measures were economically feasible in all regions of Europe and it underlines the importance of carefully choosing the most beneficial measures for each region and even farm.

Further, SmartSOIL, through stakeholder consultation and workshops identified barriers to and incentives for applying soil carbon management measures. The stakeholders for SmartSOIL included farmer and farmers' representatives, land managers, the advisory and extension services, and policy makers. Through stakeholder consultation SmartSOIL identified and range of technical, agronomical, economic, political, social, and cultural barriers to implementing soil carbon management measures. Incentives for implementing soil carbon measures were also explored and economic motivations were found to be a particularly strong driver for farmers' cropping and crop rotation decisions.

The results from data analysis from the long-term experiments and stakeholder consultations were implemented in the SmartSOIL Decision Support Tool and the SmartSOIL Toolbox, which will aid farmers and advisors in choosing the most appropriate strategy for soil carbon management. Such strategies aim to ensure continuously high yields while preserving soil and ecosystem services.

2 Summary description and main objectives

Soil and crop management have significant effects on soil carbon flows and stocks and hence on soil functions and the ecosystem services that soils supply. Therefore management can be effectively used as a tool to control and direct the services. Because many ecosystems services are nonmarket goods, there is typically no incentive to improve the flow of these services, since current policies and the market focus on subsets of ecosystem services at the expense of others. This often results in short-term productivity gains at the expense of long–term sustainability of agricultural practices. Unless there is some type of incentive put in place, e.g. a carbon price, management practices to optimize crop productivity and soil carbon storage are not encouraged. There is a need for better tools to inform policy makers on which incentive schemes and policy measures would be most cost-effective under current and future environmental and market conditions to fulfil requirements for both increased productivity and soil C sequestration. Farmers and agricultural advisors require Decision Support Tools (DSTs) that can assist them in preparing appropriate farm specific plans for improved crop and soil management. The DSTs must properly address all barriers against implementation of appropriate practices.

The aim of SmartSOIL is to contribute to reversing the current degradation trend of European agricultural soils by improving soil C management in European soils of arable and mixed farming systems, covering intensive to low-input and organic farming systems. This entails 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, such as soil fertility, biodiversity, water quality, nutrients cycling and other soil ecosystem services, and soil carbon sequestration and storage.
- Development and delivery of the SmartSOIL Decision Support Tool and guidelines to support novel approaches, techniques, and technologies adapted to different European soils and categories of beneficiaries such as farmers, farm advisory and extension services, and policy makers.

To achieve these two main objectives nine specific objectives were formulated, which resulted in a number of deliverables. The nine specific objectives are listed and described in in section 3.

The SmartSOIL project generally followed two strands of research. 1) Data analysis to identify and quantify soil carbon management measures and the effect of these, and 2) stakeholder consultation and workshops to identify barriers to and incentives for implementing soil carbon management measures.

To identify the farming systems and agronomic practices used in Europe and their effect of soil carbon, and thus on ecosystem services, SmartSOIL analysed data from long-term experiments. These long-term experiments, which represent typical cropping systems corresponding to their region, have implemented a range of different relevant soil carbon management measures, including minimum and zero tillage, application of animal manure, residue incorporation, cover and/or catch crops, and mineral fertiliser input. These management measures were all evaluated against changes in soil carbon stock, and in terms of crop yield. Further, an analysis of the cost-effectiveness of each measure was carried out. Such an analysis is very important if the farming community is to change farming practice and implement soil carbon measures. The specific measures and crop combinations and the total effect of these vary between regions, but some measures are applicable to all regions. Minimum tillage, conservation agriculture and manure application are estimated to be highly cost-effective even if slight yield loss occurs, because of the reduced input cost, i.e. a reduction in fuel consumption and mineral fertiliser application. Inclusion of legumes in crop rotation appears to be cost-effective due to decreased mineral fertiliser input, but the analysis carried out in SmartSOIL did not consider total impact over the course of a rotation and more research into this is needed. In terms of carbon increase residue management have a high potential, but it may result in loss of gross margin due to foregone revenue from selling straw as a by-product. Cover crops were, under mean yield impact assumption, estimated to result in a large reduction in gross margin due to the additional cost of seeds and cultivation. However, the effect of cover crop is highly sensitive to the impact on yield, and high yield impacts improved the cost-effectiveness for some crops in some regions. The effect of each soil carbon management measure and the effect of crop rotation vary between regions and it is therefore important to choose the most appropriate measure in relation to the individual region.

Another important issue, apart from the effect of different soil carbon management measures is the barriers to and incentives for implementing the measures, and in which socio-economic context these should be evaluated. “What’s in it for the farmers and farming community?” In order to elucidate this question a series of stakeholder consultations and workshops were held. The stakeholders included farmer and farmers’ representatives, land managers, the advisory and extension services, and policy makers. Through these consultations and workshops SmartSOIL identified a variety of barriers to and incentives for implementing soil management measures. The barriers for implementing the measures, which may be relevant even if a certain measure is assessed as cost-effective and will contribute to an increased gross margin, vary between regions and are of technical, agronomical, economic, political, social, and cultural nature. Technical and agronomical barriers may be regional climatic and environmental conditions, which are specific to specific crops or cropping systems. A technical barrier may also be the need to acquire new machinery and an additional cost of operation and input which may limit implementation of certain measures especially for smaller farmers. Through consultation with farmers SmartSOIL also found that there was a general reluctance to change from region specific traditional farming practices, especially in older farming communities, and must be addressed with appropriate sharing of knowledge and advice in the community. This was also underlined by the fact that farming communities experienced a lack of appropriate information and regional advisory services available to farmers for consultations on the benefits of soil carbon management practices. A strong motivational factor for farmers’ decision on crop and crop rotation, and therefore to implement soil carbon management measures, were gross margin or profit, which not always equate with higher yield. As opposed to this sustaining soil fertility and resilience to climatic variations were ranked low among motivational factors. There are, however, a number of opportunities to encourage the implementation of soil carbon management measures, with the most dominant being the need to provide incentives to implement the measures. The incentives to implement soil carbon management measures may take different forms, such as subsidies to purchase necessary machineries, the inclusion of the measures as Agro-environmental measures, or an economic incentive related to reducing greenhouse gas emissions.

All the information and knowledge gathered from the long-term experiments and from the stakeholder consultation and workshops were analysed and implemented into the SmartSOIL Decision Support Tool (DST) and the SmartSOIL Toolbox. These are the main outputs from the SmartSOIL project and are available from the website - www.smartsoil.eu. The SmartSOIL DST will help farmers and advisors identify cropping systems and farming practices that optimise crop productivity and soil carbon sequestration. The SmartSOIL DST was developed on top of the existing C-TOOL model, showing the effects of short- and long-term soil management on soil carbon and crop productivity, and the Yield model, using a nitrogen fertiliser response curve. The main incentive for developing a new DST was the exiting models generally did not take soil carbon management into account. The SmartSOIL DST lets farmers, land managers, advisors and extension services, and regional policy makers test the interactions between soil management and soil carbon levels, and thus on a range of ecosystem services, which will aid in choosing the most appropriate soil carbon measure adapted to European soils and bio-geographic conditions. This addresses the issue of farmers generally being reluctant to learn, invest in, and use new tools unless there is a clear documented benefit, in terms of higher yield and/or increased gross margin. Using the SmartSOIL DST a farmer or farming advisor can select the appropriate region, a reference scenario with no soil carbon management practices, and different management practices, such as cover crops, residue management and/or addition of organic manure. The DST will use this input to predict the soil carbon trends over a 30 year period as well as the yield response to N input for the different active scenarios. Economic costs and benefits and ecosystem services from implementing the alternative practices as well as the cost-effectiveness of the measure in building soil carbon and reducing greenhouse gas emissions are provided for the wider EU.

3 Main S & T results/foregrounds

The SmartSOIL project formulated nine specific objectives, which was reported in 32 deliverables. The deliverables are available on the SmartSOIL project website. In the following the outcome of the work on each of these objectives are described.

3.1 Crop and soil management effects

To quantify crop and soil management effects in different farming systems on vital soil functions, including effects on crop yield levels and stability and on soil C sequestration

To study the crop and soil management effects on important soil functions, such as crop yield, soil stability, and soil C sequestration, which are all important ecosystem services, data from 20 long-term field experiments (LTE) from across Europe were collected. The number of different treatment varied from 2 to 16 with regard to among others the application level of mineral fertilizer and animal manure, crop residue incorporation, tillage, and cropping system. In addition the management factors information about soil type, yield, and climate data were available. All the data collected from the LTE's were organized in databases and made available to all SmartSOIL partners *via* the website internal area. LTE data are not publicly available and will not be so unless agreed upon with the institutions contributing the LTE data.

Analysis of the LTE data has led to seven scientific papers, of which three is published while the four others are in preparation.

- Taghizadeh-Toosi, A., J.E. Olesen, K. Kristensen, L. Elsgaard, H.S. Østergaard, M. Lægdsmand, M.H. Greve and B.T. Christensen. 2014. Changes in carbon stocks of Danish agricultural mineral soils during 1986-2009. Eur. J. Soil Sci. 65, 730-740.

Abstract: To establish a national inventory of soil organic carbon (SOC) stocks and their change over time, soil was sampled in 1986, 1997 and 2009 in a Danish nation-wide 7-km grid and analysed for SOC content. The average SOC stock in 0-100-cm depth soil was 142 t C ha^{-1}, with 63, 41 and 38 t C ha^{-1} in the 0-25, 25-50 and 50-100 cm depths, respectively. Changes at 0-25 cm were small. During 1986-97, SOC in the 25-50-cm layer increased in sandy soils while SOC decreased in loam soils. In the subsequent period (1997-2009), most soils showed significant losses of SOC. From 1986 to 2009, SOC at 0-100 cm decreased in loam soils and tended to increase in sandy soils. This trend is ascribed to dairy farms with grass leys being abundant on sandy soils while cereal cropping dominates on loamy soils. A statistical model including soil type, land use and management was applied separately to 0-25, 25-50 and 50-100 cm depths to pinpoint drivers for SOC change. In the 0-25 cm layer, grass leys added 0.95 t C ha^{-1} year^{-1} and autumn-sown crops with straw incorporation added 0.40 t C ha^{-1} year^{-1}. Cattle manure added 0.21 t C ha^{-1} year^{-1}. Most interestingly, grass leys contributed 0.58 t C ha^{-1} year^{-1} at 25-50 cm, confirming that inventories based only on top-soils are incomplete. We found no significant effects in 50-100 cm. Our study indicates a small annual loss of 0.2 t C ha^{-1} from the 0-100 cm soil layer between 1986 and 2009.

- Oelofse, M., B. Markussen, L. Knudsen, K. Schelde, J.E. Olesen, L.S. Jensen and S. Bruun. 2014. Do soil organic carbon levels affect potential yields and nitrogen uptake efficiency? An analysis of winter wheat and spring barley field trial data from Denmark. Eur. J. Soil Sci. 66, 62-75.

Abstract: Soil organic carbon (SOC) is broadly recognised as an important parameter affecting soil quality, and can therefore contribute to improving a number of soil properties that influence crop yield. Previous research generally indicates that soil organic carbon has positive effects on crop yields, but in many studies it is difficult to separate the effect of nutrients from the effect of SOC in itself. The aim of this study was to analyze whether the SOC content, in itself, has a significant effect on potential yields of commonly grown cereals across a wider range of soil types in Denmark. The study draws on historical data sets from the Danish national field trials consisting of 560 winter wheat (Triticum aestivum L) trials and 309 spring barley (Hordeum vulgare L.) trials conducted over the past 20 and 17 years, respectively. We hypothesised that for these two crops, the potential grain yield, the yield with no fertiliser N application and the N use efficiency would be positively affected by SOC level. A statistical model was developed to explore relationships between SOC and potential yield, yields at zero N application and N use efficiency (NUE). The model included a variety of variables and aimed to elucidate the sole effect of SOC by controlling for potential confounding variables. No significant effect of SOC on potential winter wheat was found, whilst for spring barley, only for the course sandy loam soil type was a borderline significantly positive effect of SOC on potential yields found. The relationship between unfertilized plot yields and SOC was positive for winter wheat, although not significant, whilst for spring barley a significant positive effect of SOC was found only for the coarse sandy soil type, and a borderline significant positive effect of SOC was found for the coarse sandy loam soil type. A significant negative relationship was found between SOC and NUE for both winter wheat and spring barley. Based on the large dataset analyzed, we cautiously challenge the importance of SOC in contributing to crop productivity in contexts with similar soils and climate, and we speculate that in situations where nutrient limitation does not occur, SOC levels above 1% may be sufficient to sustain yields. In light of the findings presented in this study, further work should be conducted which can further elucidate the effect of SOC on yields.

- Taghizadeh-Toosi, A., B.T. Christensen, N.J. Hutchings, J. Vejlin, T. Kätterer, M. Glendining, J.E. Olesen. 2014. C-TOOL: A simple model for simulating whole-profile carbon storage in temperate agricultural soils. Ecological modelling 292, 11-25.

Abstract: Soil organic carbon (SOC) is a significant component of the global carbon (C) cycle. Changes in SOC storage affect atmospheric CO2concentrations on decadal to centennial timescales. The C-TOOL model was developed to simulate farm- and regional-scale effects of management on medium- to long-term SOC storage in the profile of well-drained agricultural mineral soils. C-TOOL uses three SOC pools for both the topsoil (0–25 cm) and the subsoil (25–100 cm), and applies temperature-dependent first order kineticst o regulate C turnover. C-TOOL also enables the simulation of14C turnover. The simple model structure facilitates calibration and requires few inputs (mean monthly air temperature, soil clay content, soil C/N ratio and C in organic inputs). The model was parameterised using data from 19 treatments drawn from seven long-term field experiments in the United Kingdom, Sweden and Denmark. It was found that the initial SOC content had to be optimised for each experiment, but also that one set of values for other model parameters could be applied at all sites. With this set of parameters, C-TOOL can be applied more widely to evaluate effects of management options on SOC storage in temperate agricultural soils. C-TOOL simulates observed losses of SOC in soils under intensive agricultural use and the gain in SOC derived from large inputs of animal manure and inclusion of perennial grassland. The model simulates changes in SOC for the entire profile, but lack of data on subsoil SOC storage hampers a proper model evaluation. Experimental verification of management effects on subsoil C storage, subsoil C inputs from roots, and vertical transport of C in the soil profile remains prioritised research areas.

- Baby, S. et al: Soil carbon content as affected by management and climate in Europe. *In prep.*

The paper describes the result of a statistical analysis of the LTE database. The paper concludes that it is possible to model and predict the development in soil carbon over time as a function of climate, carbon input, crop rotation, and tillage intensity.

- Ferrise, R, Antichi, D., Thomsen, I.K., Ventrella, D., Mazzoncini, M., Moriondo, M., Olesen, J.E., and Bindi, M.: Crop yield and N utilization as influenced by C flux and stock components: a European multi-site experiment. *In prep.*

This paper describes the new experiments made at three locations in Europe for exploring the SmartSOIL concept of C flows and C stocks in trying to isolate the effect of management from those of soil organic matter content. The approach surmises that flows and stocks play separate and different roles in relation to soil properties, soil functions and crop productivity, and that soil management can be designed to optimize either flow-derived or stock-derived functions.

- Ravnskov, S.: Arbuscular mycorrhiza fungi as soil health indicator. *In prep.*

This paper investigates the possible link between carbon sequestration and soil health. The objective was to study the influence of incorporation of organic matter, mechanical soil management, and crop rotation on soil health as measured by presence of a soil health indicator organism; arbuscular mycorrhizal fungi (AMF). Overall, the work showed a positive correlation between amount of incorporated straw and AMF inoculum potential of the soil, revealing that straw incorporation increased both soil health and the soil microbial carbon pool.

- Schelde, K., I.K. Thomsen, E.M. Hansen, M. Bindi, R. Ferrise, B. Ghaley, P. Kuikman, P. Smith, and J.E. Olesen: Does soil organic matter contribute to crop yield beyond nitrogen supply? *In prep*

This paper explores how varying C stocks and flows affect crop yield responses to varying inputs of fertilizer N. Two published studies with varying soil C stocks influenced by previous long-term management consisting of incorporated organic matter and the use of catch crops were identified and re-examined. Subsequent to the establishment of varying soil C stock and labile C pool levels, the two studies terminated their SOM input treatments and determined yield-to-N response curves over 3-4 growing seasons. The experimental approach enabled us to look for possible effects of SOC on crop productivity that are beyond effects of indirect N supply to the crops.

In addition to the above described analysis of the LTE data, SmartSOIL also aimed at developing a simplified model of management on soil carbon flows and stocks. A simple model was developed to simulate crop yield – soil carbon stock/flow under diverse climatic conditions and soil and crop management practices. Simply put, the simple carbon model consists of two linked models: a) A soil carbon prediction model and b) a yield trend prediction model. The soil carbon prediction model that distinguishes soil C in topsoil and subsoil as affected by soil carbon inputs and management was developed and tested against the LTE database. The model describing effects of soil carbon management on crop yield takes its departure in the response of crop yield to N fertiliser rates and adjusts parameters describing this curve depending on soil C flows and stocks, considering how these affect crop N supply as well as crop water supply and health aspects.

The work on the simple model resulted in two papers describing the soil carbon prediction model and the yield trend prediction model, respectively.

- Olesen, J.E., Smith, P., Porter, J.R., Yeluripati, J., Ghaley, B.B., Schelde, K., Baby, S., Ferrise, R., Kuikman, P., Lesschen, J. A simplified model for assessing soil carbon management effects on soil carbon stocks and crop yield. *In prep.*

Soil organic matter content (or soil carbon) is a key parameter for nutrient supply to crops in farming systems. It is also essential to maintain water and nutrient function in the soil, to stabilize the soil and protect it from erosion, and to enhance the biodiversity of the soil. Consequently low carbon content in the soil may threaten productivity or even collapse the cropping system itself. Therefore, it is crucial to identify which levels of carbon is critically low, as well as to which extent and in which area of Europe these levels might occur. This knowledge will help evaluate farming systems' ability to handle external stresses and to apply appropriate strategies to restore these areas. Two indicators of critically low soil carbon were identified: "Soil potential stability indicator (*n*)" and the "Soil carbon balance indicator". The former indicator is derived from the ratio between clay and carbon content of the soil. This indicator enables a classification of soils in terms of the potential carbon protection capacity. This relies on the interaction between soil carbon and the mineral fines. The latter indicator is a model used to estimate carbon inputs from crops, crop residues, and manure a regional scale. These two indicators provide relevant information on areas where declining soil carbon may jeopardize good functioning of European farming systems. The combination of the two indicators enable us to identify areas in potential risk and, combined with site specific information, define measures to improve the soils' carbon storing capacity and to protect it from degradation. Result from this project show that many European areas, despite them being at risk of degradation, have a high potential for increasing soil carbon through an appropriate planning and implementation of farming practices. The broad range of information that can be retrieved and the related considerations that can be made suggest that successful mitigation policy needs to be focused on strategies that are region specific and provide flexibility to facilitate SOC management practices adoption and SOC content enhancement. Once areas under risk are identified, risks have to be regionally reduced by setting simple objectives which involve farmers and stakeholders in the process. The current policies that promote agricultural mitigation have also to provide regional information of cost and incentives associated to the management adoption.

This objective was mainly reported in the deliverables 1.1, 1.3, and 2.4.

3.2 Improving crop-soil simulations models

To improve current crop-soil simulation models with respect to e.g. effects of long-term soil and crop management in farming systems on soil C and nitrogen flows, soil C stocks and GHG emissions

When the SmartSOIL project was initiated there were no simulation models available that were able to directly simulate crop yield responses to changes in soil carbon management. The available models all failed in linking crop yield to changes in soil structure as well as organic matter turnover effects on soil mineral nitrogen, and a new approach of linking soil carbon to soil properties and crop productivity was required. As part of the SmartSOIL project a new combined modelling approach was identified by merging a crop growth model, Daisy, with four of pedotransfer models developed from different European datasets. The Daisy model was chosen due to the robustness of the model, which means that it can be applied with a minimum of data in general production systems. The effects of different soil carbon levels on crop production were tested using the combined models for a range of years and wet and dry growing seasons. The work on the combined models are published in the paper:

- Ghaley, B. B, H. Wösten, J.R. Porter, J.E. Olesen, K. Schelde, S. Baby, Y.K. Karki, C.D. Børgesen, P. Smith, J. Yeluripati, R. Ferrise, M. Bindi, P. Kuikman, J. Lesschen. Simulation of crop yield responses to varying soil properties and functions as affected by long-term carbon management. *In prep.*

The main results from the model analysis were that 1) the four different pedotransfer functions showed similar relative changes in plant available water for varying soil carbon content, and 2) there were no effect on crop yields at high fertilizer N inputs of a moderate change in soil carbon, for a northern European site with limiting soil water stress. There was, however, an effect of changes in soil carbon for lower fertilizer N inputs, where higher yields were obtained with an increase in soil carbon. This suggests that soil carbon can have significant effects on crop productivity at low fertilizer N supply levels, which suggests that building a soil carbon pool might allow less fertilizer N to be used to achieve the same yield.

Ongoing work with two models, DNDC and DayCent, on data from four long term experiments are exploring their ability to simulate soil carbon dynamics under different management practices, and to identify factors controlling soil carbon dynamics and their sensitivity to environmental and management drivers. Initial conclusions suggest that soil carbon models are highly useful for management practices that control soil carbon dynamics, and both models performed well in predicting soil carbon dynamics and crop yields. The models are therefore very useful tools for land managers and policy makers when recommending farming practices to increase soil carbon levels in agricultural soils. More work, however, should be done on the models to enhance their performance with regard to residue management, since these practices showed a less good fit with observed yield and soil carbon dynamics.

The outcomes are mainly reported in deliverables 1.2 and 1.4.

3.3 Improved crop production systems

To identify improved crop production systems with higher resilience to environmental change and reduced environmental impacts, including lower GHG emissions

Soil management can significantly affect soil carbon flows and stocks, the risk of soil erosion and degradation, and greenhouse gas emissions. As farming systems throughout Europe have been changing over the past decades, and continue to change. The changes are driven by various economic, social, and demographic factors and changes in consumer preferences and demand. It is necessary to identify and characterize typical European farming systems with relevant crop and soil management. With such characterisation of European farming systems in place it is possible to identify which systems are more resilient to environmental change. The farming systems and practices examined indicated a range of mitigation potentials and trade-offs in terms of costs, technical or societal issues, but also the possibility of positive side effects such as wider environmental benefits, for example to biodiversity. For cropland practices studied in SmartSOIL farming practices including catch cops and reducing fallow periods was shown to increase soil carbon, reduce erosion, and also reduce emission of greenhouse gases (GHG), in particular N2O, while reducing the need for fertiliser N. It was also shown that reduced or conservation tillage was preferable compared to no tillage and such practice will increase soil carbon while being less likely to decrease yield or increase GHG emissions. Reduced or conservation tillage can be practiced in combination with residue incorporation for increased positive effect.

When focusing on GHG emissions fertiliser input is one of the main drivers, and any measure to reduce fertiliser input has high mitigation effect, but the measures, such as fertiliser type and precision farming technique, must be carefully chosen to match the soil type and specific crop. Rotational cropping will increase soil carbon storage and decrease the demand for fertiliser N, and thus GHG emission, if the crop selection is optimised particular by including N fixing crops in the rotation. This is already practiced in many EU areas. Taking land out of crop rotation and changing to permanent crop such as grassland or perennial bio-energy crops may have greater effect on increased soil carbon and decreased GHG emission, but this effect may be offset if the land remaining in crop productions is farmed more intensively. A major contributor to GHG emissions is the treatment, storage, and disposal of animal wastes from agriculture, and practices that mitigate these are highly valuable. With regard to storage, choosing an appropriate storage method for local conditions can greatly reduce emissions, and may be as simple as covering the storage tank. In terms of application measures there are no clear consensus on best practice. When taking cost into account, manure spreading followed by shallow incorporation may be best practice.

Many factors come into play when discussing best practice in farming systems and work done within the framework of SmartSOIL highlight the importance of taking all GHG emissions and evaluating the total Global Warming Potential of a system into account when evaluating farming approaches with minimal environmental impact or even positive impact. To develop an understanding of soil sustainability and resilience SmartSOIL introduced the concept of natural capital. Natural capital is related to the soil carbon stock, as measured by soil carbon levels, in terms of quality and/or quality of a natural asset and its ability to maintain a flow of ecosystem services. It is, however, difficult to measure the relationship between soil natural capital and ecosystem services, because of the complexity of the ecosystem processes involved. In SmartSOIL we have focused on soil carbon stock, but as there is no direct flow from capital stock, in this case soil carbon, to ecosystem services, it is clear that soil sustainability and resilience are very complex and must be measured using several indicators. As soil carbon is a key factor underpinning the soils’ ability to maintain important ecosystem services, SmartSOIL has identified a number of management measures and their associated soil carbon accumulation rates and impact in ecosystem services, crop yields in particular. However, the link between ecosystem services and soil carbon may be weak and even further masked by management and

capital input measures, e.g. mineral fertiliser N, which makes reductions in sustainability and resilience difficult to distinguish. SmartSOIL used existing data on European farming systems to develop an account for European Soil Natural Capital, which in combination with farming practices will allow the identification of areas at risk and potential policy responses.
The outcomes are mainly reported in deliverables 2.1, 2.2, and 3.5

3.4 Economically efficient management measures

To identify management measures that are effective in their biophysical objectives and that are economically efficient.

A key message from the stakeholder interview was that farmers are reluctant to learn, invest in, and use new tools unless there is a clear documented benefit. Further, the benefits of changing farming practice must be economically efficient. It is therefore important to understand the economic implications of changes in soil management: monetary valuation is concerned with changes in ecosystem service flows that are related to changes in stocks or natural capital, such as soil carbon. While values of changes in flows provide input into cost-benefit assess for example, policy interventions aimed at increasing SOC levels, they do on their own not provide the information required to assess the sustainability of such interventions and management changes. The latter requires information on stocks of ‘soil assets’ and the degree of substitutability of natural and manmade elements of stocks to optimise service flows over time. In this context, SmartSOIL attempted to clarify some of the socioeconomic contexts and frameworks for developing soil science, in which the concept of ecosystem services has been developed in parallel with the concept of soil functions. Soil function should be viewed as bundles of individual soil processes that contribute to a final valued ecosystem service. Ecosystem services are a complex interaction of multiple processes, and it is important to understand the underlying biophysical complexity of the service delivery in order to establish a scientifically sound valuation of the service. This is important to identify the range of trade-offs and synergies associated with the ecosystem response to alternative land management.

When evaluating ecosystem services it is important to make the distinction between intermediate and final ecosystem services. The final ecosystem service is a service that has a direct impact on human health and well-being, such as productive capacity or groundwater quality, and these services are affected by often a range of intermediate ecosystem services or soil functions, such as soil structure or ion retention and exchange. It is important to identify intermediate ecosystem service outcome related to soil that are relevant to final ecosystem service in order to identify future research to understand and quantify crucial links between the two levels of ecosystem services. Within the SmartSOIL project the impacts of soil carbon and soil management on the productive capacity of land, either improving the growth conditions of crops and therefore yields, or by increasing fertiliser use efficiency, related to a reduced level of fertiliser input required for optimal plant growth, were investigated. Soil carbon and greenhouse gas fluxes associated with alternative soil management regimes will ultimately contribute to a better understanding of the impact of soil carbon on important ecosystem services which will enable and assessment of associated trade-offs and synergies in intermediate and final ecosystem service provision.

Focussing on the soil carbon stock a cost-effectiveness analysis was carried out in the SmartSOIL project. This analysis was based in case study region and indicates that there is a potential for implementing soil carbon management practices that can produce benefits to farmers in terms of improved gross margins. A list of feasible measures for increasing soil carbon was developed and evaluated against farm or crop type, soil type, and region. This list focused only on measures that may increase soil carbon and does not take into consideration that a certain measure may have a negative effect on final ecosystem services unless countered by other measures. The list included cover or catch crops, zero tillage, minimum or conservation tillage, residue management, legumes, crop rotation, fertilisation with animal manure, optimised fertilisation, and green manures. The specific measures and crop combinations vary between regions, but some measures are applicable to all regions. Farming practices, such as minimum tillage and manure application are estimated to be highly cost-effective even if slight yield loss occurs, because of the reduces input cost. Input costs include the reduction in time and fuel needed relative to conventional tillage and reduces mineral fertiliser cost. Inclusion of legumes in crop rotation appears to be cost-effective due to decreased mineral fertiliser input, but the analysis carried out in SmartSOIL did not consider total impact over the course of a rotation. Residue management and incorporation has a high potential for soil carbon increase, but this may result in a loss of gross margin due to foregone revenue from selling straw as a by-product. Cover crops were, under mean yield impact assumption, estimated to result in a large reduction in gross margin due to the additional cost of seeds and cultivation. However, the effect of cover crop is highly sensitive to the impact on yield, and high yield impacts improved the cost-effectiveness for some crops in some regions.

The outcomes are mainly reported in deliverables 3.1 and 3.2.

3.5 Modified crop and soil management

To analyse the effects of introducing new or modified crop and soil management on a range of ecosystem services at different scales for Europe

The scientific research in SmartSOIL has mainly focussed on the alternative measures to increase soil carbon in arable systems, and thus farming system mitigation potential and resilience. In the previous section a range of soil carbon increasing measures were identified and listed. Many of these measures can be applied simultaneously, and the aggregate contribution of the measures comprises the full mitigation potential. The full mitigation potential is the levels and values of soil carbon that could be realised if all measures were fully implemented in all biophysical contexts. However, in most regions the implementation level is constrained by economic, policy, and other institutional and behavioural constraints that limit the potential to something less than the full potential. A cost-effectiveness analysis is necessary and likely to be an important criterion in policy development. Cost-effectiveness analysis is also important when evaluating a nations' total carbon emission, as it may be used to decide whether such measures are worth targeting or if similar or higher reduction are cheaper to implement in other sectors, such as the transport of energy sector.

When evaluating the effects of introducing modified soil and crop management measures, it is important to focus on the economic trade-off space between effects on yield and input costs of the measure aimed at enhancing soil carbon stocks and to maintain soil fertility, and as such providing important ecosystem service. To investigate the financial impact of soil carbon management SmartSOIL used a farm level model for groups of farmer in three regions of Europe. Despite very promising results, the findings point to further research needs with respect to the investigated trade-off space, and have implications for agricultural policy design aimed at enhancing soil carbon stocks under a changing climate. Within SmartSOIL the financial impact of soil carbon management were investigated for the range of measures identified and described in the previous section. The results show that the financially viability of soil carbon management measures are highly variable and dependent of regional differences and therefore that such measures are carefully selected and adapted to each farmer and region. Residue management can be expected to have a negative impact on farm gross margin due to the foregone value of selling the residue and the little or moderate effect on yield. Tillage management was found to have a positive impact farm gross margin, but the type of management that resulted in the positive effect, i.e. zero or minimum/conservation tillage, varied between regions, underpinning the importance of carefully choosing the measure to each region and farm type. The results further show, that there is limited variability in impacts of soil carbon measures between different farm types. All of the crop farms are assumed to be on similar soil type and have very similar management practices. The only major difference between the farms is size of farm and scale of production. Our assumption behind the changes in crop yields and costs of production is generalised across all farm types. A more detailed set of assumptions for each farm type would most probably bring out some variability in the impacts of the soil carbon management measures on different farm types.

A sensitivity analysis was carried out as part of the study and showed the relative robustness of soil carbon management measures from a financial perspective. However, the finding from this study should not be used as a predictive tool for policy makers and farmers. Rather, the objective was to demonstrate important considerations that affect the uptake and profitability of soil carbon management measures. While these considerations need to be carefully evaluated by decision makers on a case-to-case basis, SmartSOIL has identified soil carbon measures that are most robust to changes in underlying assumptions regarding yield and nutrient availability effects. The robustness of farm gross margin impacts differ across soil carbon management measures in different regions. This point to the need for a more detailed understanding of local environmental and farm management factors that affect yields and input costs. The absence of such detailed information being available to farmers risk adverse farmers tend to choose the more robust soil carbon measure, such as cover crop or animal manure application, despite lower projected impact on farm gross margin, within the trade-off space between effects on yield and input cost, compared to alternative soil carbon management measures. Other measures with lower robustness, more difference between the projected upper and lower bound, may be less attractive to farmers even if the potential gross margin is higher.

The model used in the SmartSOIL project was based on one year of data only and results therefore rely heavily on the performance of the farms that year. It also assumes profit maximising behaviour of the farmers, but farmer behaviour, especially in relation to soil management, may also be motivated by factors such as perceived workability of the soil or soil health for future generations. The effect of such motivation is unclear and needs further investigations. When evaluating different soil carbon management measures, especially in relation to policy making, it is important to remember that from a farmers' perspective the actual financial impact of a given soil carbon management measure is unknown and to some extent dependent on external factor beyond the farmers' control, such as weather and market price, which makes investment into changes in management a risky choice. This is especially true, if the given change in management is not easily implementable but requires access to capital and technology, such as new machinery. An extension to the model used in SmartSOIL should therefore incorporate an element of risk through the development of probabilistic outcomes for yield effects and costs over the years. This aspect is of interest, because soil carbon management measures may contribute to reducing yield reliability over time, for example by improving the water holding capacity of the soil and therefore the capacity to overcome longer periods of drought. This may become increasingly important in the context of climate change adaptation. Before using soil carbon management measures in a broader policy perspective, the performance in relation to changes in soil carbon stocks, especially in low carbon areas and in areas at risk of carbon degradation under the current management regime. Expanded models combining farm level models with a more detailed soil carbon model, or the development of regional that optimise the allocation of management measures according to economic and soil management objectives should be the topic of further research. Lastly, impacts on greenhouse gas emissions and other co-effects including improvements in water quality and water retention on the field, or biodiversity, should be assessed as the benefit to the public can play an important role in justifying government support for improved soil carbon management, or for other government intervention.

The outcomes are mainly reported in deliverables 2.3, 3.3, and 3.4.

3.6 Information needs amongst producers and advisors

To apply a participatory approach to inform the scientific work involved in the project by, e.g., identifying barriers and opportunities of management options for producers and identifying knowledge gaps and information needs amongst producers and advisors

The SmartSOIL project has identified a range of soil carbon management practices that will help sustain and increase sustainability and ecosystem services. Work within the SmartSOIL framework resulted in an evaluation of the cost-effectiveness of a range of measures and the projected impact on farm gross margin. To better understand the socio-economic context of these measures, farming communities in different regions across Europe were consulted. The initial consultation with advisors, farmers' representatives, and policy makers revealed a range of region-specific barriers and incentives to the implementation of promising soil and crop management measures and practices. Based on this initial consultation, SmartSOIL hosted stakeholder workshops in different region aiming at drawing on the expertise of advisors, farmers' representatives and leading farmer, and policy makers to better understand typical cropping systems and rotations and the associated risk to soil carbon, the most relevant soil carbon management measures and the level of implementation, barriers and opportunities to implementation of cost-effective soil carbon management measures, and the requirements and needs to the SmartSOIL Decision Support Tool (DST). The stakeholder workshops led to the description of a range of cropping systems and rotation within and across region in Europe, which was based on difference in biophysical conditions, farming systems, and structural conditions of the farms. These consultations are important to understand farmers' incentives to implementing soil carbon management measures to increase sustainability and preserve ecosystem services.

Economic motivations were found to be a particularly strong driver for farmers' cropping and crop rotation decisions. Joining the Common Agricultural Policy (CAP) and urbanization may also affect farming practice decisions. Barriers to implementation of soil carbon management measures which are assessed as cost-effective and will contribute to an increased gross margin are subject to a range of technical, agronomical, economic, political, social, and cultural barriers, which vary between regions. Regional climatic and environmental conditions such as drought and wet and cold conditions may pose technical and agronomic barrier affecting soil carbon management measures, with regard to specific crops or cropping systems. Additional cost of operation and input may limit adaptation of a specific management measure for small farmers, where large scale farmers are more like to implement such measures. In addition to technical/agronomic barriers, there was a general reluctance to move away from the traditional farming practice of a region, especially in regions with an older farming community. Such social and cultural barriers are important to address with appropriate knowledge sharing in the farming community. Across all regions gross margin or profit was ranked higher as an economic motivation than maximising yield while resilience was ranked low among motivation factors.

Maximising profit did not always equate with increasing yield. A very important finding of the workshops was that the lack of appropriate information or regional advisory services available to farmers to explain the benefits of soil carbon management practices was highlighted as a barrier. However, there are a number of opportunities to encourage the implementation of soil carbon management measures; the most dominating of these are the need to provide incentive to implement the measures. The incentives to implement soil carbon management measures may take different forms, such as subsidies to purchase necessary machineries, the inclusion of the measures as Agro-environmental measures, or an economic incentive related to greenhouse gas emissions. Also improved advisory service support focusing on identifying how practices can maximise profits and gross margins as this was identified in all regions as the main driver of farmer decision-making.

The outcomes are mainly reported in deliverables 4.4, 4.5, 5.1, and 5.2.

3.7 Development of SmartSOIL DST

To develop an appropriate Decision Support Tool (DST) and associated guidelines for soil C and productivity management based on the results of experimentation and modelling.

A main outcome of the SmartSOIL project is the SmartSOIL Decision Support Tool (DST) which, based on a simple model, will help identify farming practices that optimise crop productivity and soil carbon sequestration. The Smart Decision Support Tool is based on knowledge from other work in the project aiming at improving the understanding and management of soil carbon in the EU. A range of existing DST's and platforms, targeting sustainable agriculture, soil and nutrient management, and climate were reviewed and evaluated to identify key success features and implementation problems. Few of these addressed soil carbon management. An overall finding of this review was that farmers are reluctant to learn, invest in, and use new tools unless there is a clear documented benefit, e.g. that most farmers lack the motivation to calculate soil carbon unless the benefits of soil carbon management are clearly indicated. Based on these reviews recommendations for the SmartSOIL DST and the SmartSOIL toolbox was formulated, which was then used in the development process. The Smart Decision Support Tool was developed using an iterative stakeholder consultation process. Stakeholder workshops were held in five case study regions and key insights from the stakeholder feedback were taken into consideration during the revision of the prototype, wherein the interface design was heavily revised to be more user-friendly and attractive.

The SmartSOIL DST provides farmers, land managers, advisors and extension services, and regional policy makers with an opportunity to test the interactions between soil management and soil carbon levels, and thus on a range of ecosystem services. The DST will help users select the most appropriate carbon management practice adapted to European soils and bio-geographic conditions. The Smart Decision Support Tool was developed on the existing C-TOOL model, showing the effects of short- and long-term soil management on soil carbon and crop productivity, and the Yield model, using a nitrogen fertiliser response curve. The SmartSOIL DST allows the user to select an appropriate region and reference scenario, with no soil carbon management practices. Using the DST it is possible to select different soil carbon management practices, such as cover crops, residue management and/or addition of organic manure, which the DST use to calculate the soil carbon trends over a 30 year period and the yield response to N inputs differ between the alternative and reference scenarios. Economic costs and benefits and ecosystem services from implementing the alternative practices as well as the cost-effectiveness of the measure in building soil carbon and reducing greenhouse gas emissions are provided for the wider EU. The recommended practices within the Smart Decision Support Tool generally build soil carbon over the long term, resulting in a decreased need for N-inputs. The optimal N-rate, or the level at which adding more N will not increase yield any further, generally decreases after having used management measures that add soil organic carbon. Building soil carbon is related to nitrogen inputs and may help enhance yields beyond those obtained with low soil carbon stocks.

The SmartSOIL DST is available at smartsoil.eu/tool in seven different languages: English, Danish, German, Spanish, Italian, Hungarian and Polish.

The outcomes are mainly reported in deliverables 4.1, 4.2, 4.3 and 5.4.

3.8 Dissemination of the SmartSOIL DST

To disseminate the SmartSOIL Decision Support Tool (DST) and develop guidelines to relevant stakeholders primarily through internet-based media.

The work carried out in connection with the objective described in section 3.6 - Information needs amongst producers and advisors, resulted in knowledge about barriers and opportunities for farmers to implement soil carbon management measures. This information helped to develop the dissemination of the SmartSOIL Decision Support Tool (DST) to have the widest possible impact of the DST and the knowledge behind it. The dissemination strategy of SmartSOIL aimed to ensure that the project outputs are communicated in a targeted, efficient, appealing and effective manner to a wide-ranging audience. This requires an understanding of the specified goals and key messages to be disseminated from the project outputs, the identification of the audience and the methods chosen to reach these audiences. The SmartSOIL project employed a targeted dissemination strategy and actions to speed up new knowledge and novel practices transfer to different types of beneficiaries including the farming community, extension/advisory services and other knowledge brokers, and policy makers. From stakeholder workshops and the work described in section 3.6 four distinctive characteristics of soil carbon management measures that need to be considered when providing advice and targeted in dissemination were identified. 1) It should be underlined that soil carbon management measurements provide multiple services in addition to production, and many of these are already promoted as part of other programmes such as those concerned with reducing greenhouse gas emission, reducing diffuse pollution, managing farm carbon, enhancing soil protection and conservation, ecosystem services, and sustainable soil management for productivity. 2) The implementation of the measures is complex and demanding, and may thus require additional training and knowledge with the farmers and advisory services. 3) The long-term horizon is important to keep in mind and it is important to underline that short term losses may have to be weathered before the benefits become apparent, which has implication for financial management and priorities. 4) The effects of the soils carbon management measures on soil and crop yield must be established convincingly to particular farmer contexts. The lack of long-term evidence to support long-tern benefits often affects the credibility of the message. In addition to these four considerations in relation to providing advice and convey information from SmartSOIL, the interviews from the stakeholder workshops resulted in principles and guidelines, when addressing farming communities.

Although the focus is on the farming community, the principles are relevant to all beneficiaries. These principles and guidelines includes the importance of providing direct evidence on how different practices affect yield and soil health, as well as using soil characteristics and indicators of soil carbon and soil health that farmers can understand and relate to. It is important to emphasise that despite trade-offs in the short term, the benefits and gross margin or profit are provided on the long-term. When conveying information and advising farmers it is beneficial to appeal to farmers' sense of moral responsibility and stewardship of the land, while providing credible and relevant, in scale, content, and timing of results, information and recognising that the most suitable measure may vary from national to regional and even to farm level. However, addressing mitigating climate change as an incentive to soil carbon management measure are counterproductive as farmers tend not to respond well to this message.

The outcomes are mainly reported in deliverables 4.4, 4.5 and 5.3

3.9 Policy development

To support EU policy development for soil protection by analysing options for including soil C management into European agricultural and environmental policies.

Part of the objective of the SmartSOIL project was to collect knowledge about agronomic practices and approaches for managing soil carbon to aid EU policy development for soil protection. This resulted in guidelines describing the most suitable practices and measures for different beneficiary groups. Stakeholders were closely involved in the development of the guidelines, through consultations and workshops throughout the project. Stakeholders were identified as agricultural advisors, farmer representatives, leading farmers, and policy makers and were selected from six regions of the EU, representing a range of biophysical, farming system, and socio-economic contexts. An important part of this work was to explore the range on awareness, extent of implementation of soil carbon measures and management practices, barriers to and incentives for changing farming practice to enhance soil carbon, and preferred format for decision support. Based on this information and feedback from subsequent stakeholder workshops, the SmartSOIL Decision Support Tool (DST) was developed along with other SmartSOIL Toolbox guides. The stakeholder consultations and workshops revealed that there were different preferences for information and format in soil carbon management amongst farmers, advisors, and policy makers. To address this, a Toolbox with different Decision Support Tool was created. The Toolbox include information on Real Life Cases and videos demonstrating implementation of different management measures, fact sheets that summarise benefits, costs and experiences with the management measures, and the Smart Decision Support Tool. This information and the Tool are mainly targeted at farmers and advisors to help identify cost effective management options to enhance crop yields and soil carbon for their particular farming systems, soils and climates.

The information gathered in the SmartSOIL project is also highly relevant for policy makers on both regional, national, and in European context. For this purpose a series of maps were created visualising a.o. soil carbon content and input, a yield effect factor, and areas at risk of degradation *via* soil carbon loss. Another outcome from the SmartSOIL project, which is presented in the Toolbox is a series of policy options to promote beneficial management practices and measures at national and EU levels. After analysing stakeholder responses, the different soil carbon measures, the cost-effectiveness of the measures SmartSOIL formulated six main recommendations for policy makers:

- Increase awareness of the role of soil organic carbon in delivering soil quality and soil fertility, and multiple ecosystem services among policy makers and address the issue in policy.
- Support pilot projects and provide incentives to farmers for implementing monitoring schemes and bookkeeping at farm level to monitor their carbon budgets (e.g. through Rural Development Programmes, European Innovation Partnership (EIP) initiatives.)
- Increase the baseline and mandatory requirements for farmers related to soil quality in the Common Agricultural Policy (CAP).
- Improve the Rural Development Programmes (RDPs) 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).
- Improve the participation of farmers and other soil stakeholders in the process of designing and implementing RDPs.
- 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.

All these recommendations are further elaborated on the SmartSOIL website.

The outcomes are mainly reported in deliverables 1.5, 3.5, 5.4, and 5.5.

4 Potential impact and main dissemination activities

The main deliverable of SmartSOIL is the SmartSOIL Decision Support Tool (DST) that will better facilitate the implementation of sustainable soil and land management measures in order to enhance farm productivity and to contribute to climate change mitigation. The DST is targeted at the key stakeholders such as farmers, farm advisors and extension services, and policy makers. It was an important objective of the SmartSOIL project to include stakeholder in the process of identifying the range of awareness, extent of implementation of soil carbon management practices, barriers to, and incentives and advice for, the uptake of practices that can enhance soil carbon stocks, and preferred formats for decision support. Throughout the SmartSOIL project the stakeholders were included in the process of developing and formulating policy recommendation and the final version of the Smart Decision Support Tool and the way information and recommendations were transferred to stakeholders, taking into account the specific needs of individual stakeholder groups. The DST therefore functions differently for the different target groups to meet their information needs and to help overcome the barriers for implementation of sustainable soil carbon management in arable and mixed farming systems in Europe. SmartSOIL further synthesizes knowledge across a range of soil, crop and socio-economic disciplines and aligns the information with current EU policies to propose measures for improving these policies for sustainable soil carbon management. This information will also feed into the process of preparing the Soil Framework Directive.

SmartSOIL has used extensive stakeholder involvement targeting the key stakeholder groups and considering the geographical and socio-economic spread in Europe to identify the barriers for and incentives to implementing sustainable soil carbon management. An important issue in this context is the calculation of costs and benefits of changes in soil carbon management, including trade-offs with other ecosystem services. SmartSOIL addressed this by linking results from biophysical meta-analyses and modelling with socio-economic analyses on monetary costs and benefits of changes in soil carbon management, considering the relevant timescales of such costs and benefits. These analyses are included in the SmartSOIL DST and in the recommendations for EU policy.

The SmartSOIL project has also analysed scenarios of future land and soil management under projected climate change across Europe to evaluate effects of soil carbon management strategies under projected future conditions with the aim to provide the scientific background for assessing needs for additional measures under projected climate change.

The specific wider impact of the SmartSOIL project is:

- Integrated scientific understanding of agricultural soil ecosystem processes and their role in promoting soil levels and underpinning crop yields.
- Contribution to halting degradation of European agricultural soils by identifying sustainable soil management and agronomic practices to increase yields and restore vital soil functions.
- Improved planning and analysis of future scenarios with a view to secure food and feed supply in a changing climate in Europe.
- Mainstreaming of sustainable management practices and technologies that tackle climate change and increase crop yield at farm level.
- Improved implementation of the EU Soil Thematic Strategy.

Since stakeholders have been involved in the process of the project from the beginning, one SmartSOIL focus was always an active and targeted dissemination of the results and conclusions. The dissemination of the project was initiated very early in the project with preliminary consultation with farmers representatives, leading farmers and policy makers to identify and explore the range of awareness, extent of implementation of soil carbon management measures, barriers for and incentives to and advice for, the uptake of practices that can enhance soil carbon stocks, and preferred formats for decision support. During the project period two stakeholder workshops were held with the above mentioned stakeholder groups to present initial finding and to get feedback on the SmartSOIL DST. The design of the SmartSOIL DST and the SmartSOIL Toolbox was presented to stakeholders during the development and feedback taken into consideration. The consultations with stakeholders also revealed a wide variety of preferences for information transfer and format on soil carbon management measures amongst different stakeholder groups. Because of this the Toolbox, contains a set of different tool which present the project results and recommendations in formats appropriate to different users.

In SmartSOIL dissemination to end users and stakeholders had a high priority throughout the project and based on consultation and interviews, it was discovered that many farmer prefer experimental evidence and often sought this from other farmers or through case studies or examples. In response to this, Real Life Case leaflets and videos were developed. These farmer stories present the learning experiences of individual farmers in each case study, setting out the benefits, cost effectiveness, drawbacks, challenges and motivations associated with implementing particular soil carbon management practices. The leaflets are available in the language of each case study region, Danish, Hungarian, Italian, Polish, Spanish, and have all been translated to English as well. The videos are available in the case study language with English subtitles. As part of the SmartSOIL project six FactSheets were prepared. Stakeholder consultation and interviews revealed that farmer and advisors, in addition to the experiences of other farmers, preferred to have technical documents with some demonstration of agronomic and economic benefits. Five FactSheets were prepared:

- Increasing soil organic matter through improved crop rotation
- Residue management: improving soil organic matter and reducing erosion
- Boosting soil organic matter content by applying manure and compost
- Boosting on-farm soil organic matter with catch/cover crops
- Conservation agriculture: Building soil organic matter and reducing production inputs

The FactSheets describe the key principles of how the practices benefit the soil and potentially crop yield. These include some scientific explanation and references to literature, and data to show farmers potential yield gains and cost savings. Graphs presenting the changes in topsoil versus subsoil carbon over time are also included. The emphasis is on how the practices benefit all aspects of the soil not just the single aspect of soil carbon.

The target audience was initially identified by the consortium at the national and European level, and the expanded through stakeholder consultation to national and regional levels. The audience of the projects' output includes farmer and farmers' representatives, land managers, the advisory and extension services, policy makers, and the scientific community.

European policy makers concerned with soil management and ecosystems services have been kept informed of the outputs throughout the project and were invited to take part in the final conference, specifically: DG for Agriculture and Rural Development, DG Research, DG Environment, DG Climate Action. Those involved in the Soil Thematic Strategy and formulation of the Road Map for Resource-Efficient Europe, the European Soil Partnership (ESP) and the Communication on Land as a Resource, were specially targeted, as well as those research bodies that support policy such as the JRC and European Environment Agency. Also on the European level, Key European networks, such as the European Initiative for Sustainable Development in Agriculture (EISA), European Conservation Agriculture Federation (ECAF), European Arable Farmers (EAF), European Forum for Agricultural and Rural Advisory Services (EUFRAS), European Council of Young Farmers (CEJA and members of Europe-wide representative bodies for farming (Copa-Cogeca, IFOAM) were targeted.

Case Study partners at the national level have been actively engaging with national and regional stakeholders, attending stakeholder workshops and were targeted with relevant project outputs and information. This continued throughout the project, with the beneficiaries including, Policy makers, authorities, environment agencies and regulatory bodies, National level relevant institutions and networks, professionals and practitioners such as land managers, users, and consultants and their respective representative bodies, intermediary, advisory, brokerage organizations, and NGOs, and Scientific representatives of research institutions and societies.

In addition, various disciplines within the scientific community have been and will continue to be kept informed of project developments, through published articles and presentations at

conferences. This also included European bodies such as the European Confederation of Soil Science Societies.
A complete list of dissemination activities is available in the 3rd period report and listed in Template A2.

5 Website address

The project website is:
www.smartsoil.eu

6 Plan for dissemination – section A

From the beginning of the project SmartSOIL had a strong focus on stakeholder involvement and an active dissemination strategy. This included early consultations and interview with stakeholders to identify the needs for information and the preferred formats for decision support. The main target group for the SmartSOIL Decision Support Tool (DST) are farmers, farm advisory services, and policy makers on both regional and national level. The results from SmartSOIL have been widely disseminated throughout the project. The SmartSOIL project applied two strands of dissemination of the project results and output. The dissemination of the specific outputs, associated with individual tasks in the project, to end-users is the SmartSOIL Decision Support Tool (DST), guidelines on the most suitable agronomic practices and approaches to optimise crop production and carbon sequestration and storage published in the form of FactSheets, and policy recommendations. These outputs were disseminated to the relevant categories of beneficiaries with an interest in sustainable soil management, namely farmers, farming communities, farm advisory services, and policy makers. The FactSheets are technical documents describing and demonstrating the agronomic and economic benefit of soil carbon management measures. Five FactSheets were produced on the following topics: “Increasing soil organic matter through improved crop rotation”, “Residue management: improving soil organic matter and reducing erosion”, “Boosting soil organic matter content by applying manure and compost”, “Boosting on-farm soil organic matter with catch/cover crops”, and “Conservation agriculture: Building soil organic matter and reducing production inputs”. These describe the key principles of how the practices benefit the soil and potentially crop yield. They also include some scientific explanation and references to literature, and data to show farmers potential yield gains and cost savings. In addition to the FactSheets, Real Life Cases from selected farmers in six different European countries are demonstrating the application of different management practices at farm level. This will supply stakeholders, here more specifically farmers, with experience on applying soil carbon management measure from other farmers in their region. Videos with the farmers in the Real Life Cases were also produced to accompany the written information. All this information is available on the project website which is accessible to the general public. The website is constructed as a SmartSOIL Toolbox, where all relevant information, output, and results are available. From this page the public can access the SmartSOIL Decision Support Tool (DST), the Real Life Cases and videos, policy recommendations, and the deliverables. The deliverables are important output reports from the projects. These are associated with specific tasks as described in the document of work for the project, and present the findings and result of the individual tasks.

The deliverables have been finished and submitted during the project period. The deliverable reports are for the most part detailed scientific presentations of the specific project objective and task and the result and implications forming the basis for both further work within the SmartSOIL project and scientific publication and knowledge sharing. In some cases the deliverable is a scientific paper, in which case it is also available to the scientific community *via* research databases. The findings from SmartSOIL will continue to be used in scientific research and in scientific publication after the project has ended. The members of the project group are all experienced researchers from 12 different research institutions and several of them are involved in other pan-European scientific networks. The links between the international partners and experience with international projects ensure that the result from SmartSOIL are widely discussed and communicated to the relevant stakeholder, and will be so in the future. The findings of SmartSOIL have increased the common knowledge of a range of different soil carbon management measures and their effect on yield and other ecosystem services. Knowledge on how to communicate and convey important scientific knowledge to specific stakeholder group has been collected and has been used to determine the format of the SmartSOIL Decision Support Tool and the associated information. In addition to the written information available *via* the website the SmartSOIL project and the results and conclusions have been presented at several international conferences, resulting in 39 presentations to an international audience. Printed flyers on the SmartSOIL findings, Real Life Cases, and FactSheets was circulated among relevant audiences and continue to be so, to ensure maximum impact of the key findings of SmartSOIL.

The scientific output of the SmartSOIL project is:

Management of agricultural soils for greenhouse gas mitigation: Learning from a case study in NE Spain / Sánchez B, Iglesias A, McVittie A, Alvaro-Fuentes J, Ingram J, Mills J, Lesschen JP, Kuikman P. Journal of Environmental Management, (2016) 170, 37-49. doi: 10.1016/j.jenvman.2016.01.003

Endospores, prokaryotes, and microbial indicators in arable soils from three long-term experiments / Paulina Tamez-Hidalgo, Bent T. Christensen, Mark A. Lever, Lars Elsgaard, Bente Aa. Lomstein. Biol Fertil Soils. doi: 10.1007/s00374-015-1057-5

Increase in soil stable carbon isotope ratio relates to loss of organic carbon: results from five long‑term bare fallow experiments / Lorenzo Menichetti, Sabine Houot, Folkert van Oort, Thomas Kätterer, Bent T. Christensen, Claire Chenu, Pierre Barré, Nadezda A. Vasilyeva & Alf Ekblad. Oecologia (2015) 177:811–821. doi: 10.1007/s00442-014-3114-4

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. doi:10.1371/journal.pone.0123869

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. Europ. J. Agronomy 66 (2015) 62–73. doi: 10.1016/j.eja.2015.02.009

Estimating the Costs and Benefits of Adapting Agriculture to Climate Change / Anita Wreford, Dominic Moran, Andrew Moxey, K. Andy Evans, Noami Fox, Klaus Glenk, Mike Hutchings, Davy I. McCracken, Alistair McVittie, Malcolm Mitchell, Cairistiona F.E. Topp, Eileen Wall. EuroChoices (14) Issue 2; 16-23. doi: 10.1111/1746-692X.12086

The economics of soil C sequestration and agricultural emissions abatement /P. Alexander, K. Paustian, P. Smith, D. Moran. SOIL 1, 331-339. doi: 10.5194/soil-1-331-2015

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