



JRC SCIENCE FOR POLICY REPORT

CAPRESE-SOIL: CARbon PREservation and SEquestration in agricultural soils

*Options and implications for
agricultural production*

FINAL REPORT

Arwyn Jones, Vincenzo Angileri, Francesca Bampa, Marco Bertaglia, Andrej Ceglar, Maria Espinosa, Sergio Gomez y Paloma, Giacomo Grassi, Adrien Leip, Philippe Loudjani, Emanuele Lugato, Luca Montanarella, Stefan Niemeyer, Guna Salputra, Benjamin Van Doorslaer, Raúl Abad Viñas, Viorel Blujdea

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CARbon PREservation and SEquestration in agricultural soils (CAPRESE soils) Options and implications for agricultural production

Report of Task 7: Final Report

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Administrative Arrangement N° AGRI-2012-0166

EXECUTIVE SUMMARY

The document is the final report of the CAPRESE Soils project (CARbon PREservation and SEquestration in agricultural soils) carried out by the JRC under Administrative Arrangement N° AGRI-2012-0166.

Key findings, recommendations and conclusions are summarised in the Executive Summary while brief overviews of each task are presented separately.

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Abbreviations and acronyms

BMP	Best Management Practice	LTE	Long Term Experiment
C	carbon	LUCAS	Land Use/Cover statistical Area frame Survey
CA	Conservation Agriculture	LULUCF	Land Use, Land Use Change and Forestry
CAP	Common Agricultural Policy	m	metre
CH ₄	methane	MS(s)	Member State(s)
CBD	Convention on Biological Diversity	N	nitrogen
CBP	Carbon Benefits Project	N ₂ O	nitrous oxide
CEC	Cation Exchange Capacity	NIR	National Inventory Report
CL	Cropland	NPP	Net Primary Production
CM	Cropland management	NT	No Tillage
CNDP	Complementary National Direct Payments	O	oxygen
CO ₂	carbon dioxide	OM	organic matter
CT	Conventional tillage	P	phosphorus
EEA	European Environment Agency	RMP	Recommended Management Practice
EC	European Commission	RT	Reduced Tillage
ECCP	European Climate Change Programme	S	sulphur
ESDB	European Soil Database	SALM	Malaysian Farm Accreditation Scheme
EU	European Union	SOC	soil organic carbon
FM	Forest management	SOM	soil organic matter
FT	Farm Type	SOWAP	SOil and Water Protection
FYM	Farmyard manure	SingleSPS	Single Payment Scheme
g	gram	SAPS	Single Area Payment Scheme
GAEC	Good Agricultural and Environmental Condition	SSSA	Soil Science Society of America
GAP	Good Agricultural Practice	STS	Soil Thematic Strategy
GEF	Global Environmental Facility	Yr	year
GHG	greenhouse gas	UNCCD	United Nations Convention to Combat Desertification
GHP	Good Handling Practice	UNFCCC	United Nations Framework Convention on Climate Change
GL	Grassland		
GM	Genetically Modified		
GM	Grassland management		
H	hydrogen		
ha	hectare		
HWSD	Harmonized World Soil Database		
HNV	High Nature Value		
INM	Integrated Nutrient Management		
IPCC	Inter-Governmental Panel on Climate Change		
IPM	Integrated Pest Management		
JRC	Joint Research Centre		
kg	kilogram		
K	potassium		
KP	Kyoto Protocol		
LOI	Loss On Ignition		

Unit of measures

Gt	Giga tonnes (10 ⁹ t) = Pg
Mg	Mega gram (10 ⁶ g)
Pg	Peta gram (10 ¹⁵ g) = Gt
ppm	parts per million
ppmv	parts per million in volume

1. Executive Summary

By integrating a range of technical skills within the Joint Research Centre, the CAPRESE project has led to a better understanding of the potential of using specific land management practices in preserving and increasing the stock of organic carbon in the agricultural soils of the European Union (EU).

The scientific literature relating to a range of agricultural carbon sequestration measures has been synthesised and evaluated for their potential applicability across the EU. It is clear that land management has a significant impact on soil organic carbon (SOC) stocks with a number of measures clearly leading to carbon emissions (e.g. the conversion of grasslands to arable cultivation, conventional tillage, the degradation of organic-rich soils through pressures such as erosion, soil sealing and compaction). Conversely, a number of practices can be used to preserve and increase SOC levels (e.g. water management in wetlands, restoring grasslands, reduced tillage, crop rotations).

A novel modelling platform developed specifically under the CAPRESE project is suggesting that existing estimates of the SOC stock associated with agricultural soils in the EU (topsoil = 0-30 cm) may have over-estimated the current pool by around 24%. The evaluation carried out under the CAPRESE project shows a topsoil SOC pool of 16 Gt., allocated as 7.4 and 5.4 Gt respectively between arable and pasture (based on the definitions from the CORINE Land Cover Database which gives agricultural areas for arable and pasture as 109 and 37 Mha).

The model has also shown that grassland conversion to cropland can have a strong negative impact on the overall C balance in the EU. However, within arable land, some promising management practices may be adopted for their potential in sequestering SOC. By effectiveness, these can be ranked as: cover crops, complex rotation > residue management, and reduced tillage. However, their effect was strongly dependent on the spatial and temporal extent considered.

The scenarios used in the modelling exercise clearly show strong regional differences in the performance of measures and that there is no single optimum measure.

An implementation scenario of a 12% uptake of mitigation measures (2% for arable to grass conversion, 2% for residues incorporation, 2% for reduced tillage, 2% for a combination of reduced tillage + residues, 2% for ley in rotation and 2% for cover crops) gave a cumulated sequestration value (as CO₂ equivalent) of 101 Mt by 2020. A significant proportion of EU

emission targets. Increased areas and variation in implementation patterns could give rise to higher values.

Simplistic scenario analysis shows that on the basis of a conservative implementation of mitigation measures, a SOC stock with a perceived trading value of €500 million could be established by 2020. At farm scale, this could equate to between €9 - €36 ha⁻¹ yr⁻¹ depending on local conditions and specific mitigation measure, in addition to existing agricultural returns.

The main aspects of each work package are summarised as a self-standing chapters.

2. Task 1: Analysis of the current situation

The scope of Task 1 was to describe the current carbon (C) stocks in the agricultural soils of the EU in relation to the main cropping systems and describe existing soil carbon management practices that have a potential to preserve and sequester soil organic carbon (SOC).

Task 1 was divided into two parts.

Part 1 gave an introduction to science of SOC dynamics and presented an overview of the state of SOC stocks in the EU on the basis of current scientific literature. Specific attention was given to land use, land cover change and policies that affect SOC stocks at both EU and international levels. Particular detail was placed on the importance of land use changes (in particular loss of grassland and loss of agricultural land to urbanisation, transport, energy infrastructure development, etc.). The report of Task 1 presented an overview of the estimates of GHG emissions that MS report under the UNFCCC and the Kyoto Protocol and complementing national analyses regarding estimates for emissions and removals in the base year 1990.

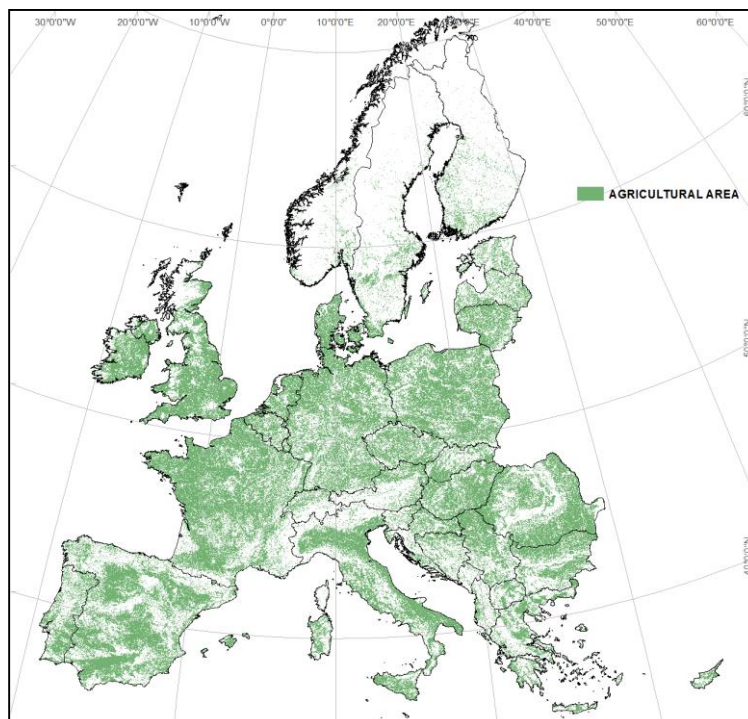
The key messages to emerge from the Task 1 Part 1 report were as follows:

- Soil is a significant, long-term reservoir of organic carbon that has accumulated through the decomposition of organic matter, emissions from roots and the activities of soil-dwelling organisms such as bacteria.
- The amount of organic carbon (OC) in soil varies according to the local climate, soil characteristics, land cover and how the soil is used. In mineral soils, SOC levels generally decrease with depth with highest concentrations in the topsoil (e.g. 0-30 cm).
- The highest levels of OC are found in organic soils (also known as peat). However, their distribution is limited to favourable topography, climate and land management practices.
- Notable levels of OC can also be found in mineral soils under permanent grasslands or woodlands, especially in temperate or cool and humid climates.
- Mineral soils across large parts of EU tend to have low levels of organic carbon (<5%).
- It is generally accepted from modelling exercises that the soils of the EU store around 73 Gt of OC, of which 21.5 Gt are associated with agricultural land. This breaks down as 12.5 Gt on the soils of arable land and 8.5 Gt on soils under pasture. However, there are great uncertainties in assessing the stock of soil organic matter across Europe.
- A major source of uncertainty is the lack of coherence on agricultural classes in spatial datasets. For example, information on the extent and type of grassland management hampers assessments and gives rise to conflicting estimates of the extent of agricultural land and thus, SOC stocks. National agricultural statistics are reported at NUTS 2 level which is too coarse for biogeochemical modelling. Conversely, land cover information is available for almost all EU Member States at high resolution but lacks detailed agricultural criteria grassland usage.
- Modelling is currently the only method to derive pan-European stocks. Models also show that climate change will lead to variations in SOC levels in relation to changing precipitation and temperature patterns.

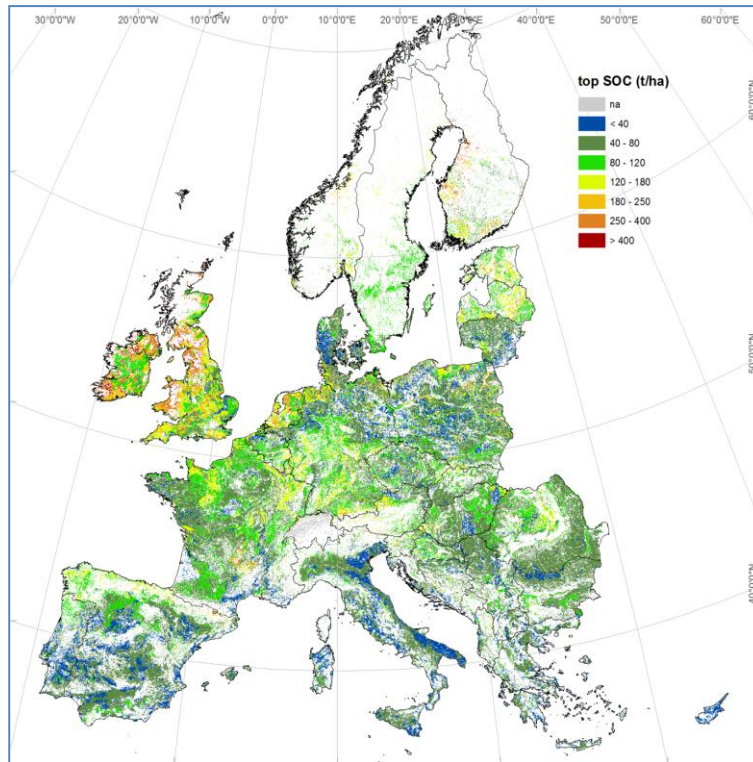
- Land management has a notable impact on the fluxes of greenhouse gases, in particular carbon dioxide (CO₂). Several agricultural activities have been shown in scientific literature to sequester carbon in soil.
- The conversion of land from natural vegetation (e.g. woodland, grassland) to arable farming leads to a gradual decrease in SOC content over time. Primarily this process is due to the oxidation of carbon during tillage and the removal of organic matter through harvesting. This aspect is significant when permanent grasslands or woodland are converted to arable use.
- Peatlands are the major SOC stores in the EU. The preservation of peatlands is an effective mechanism to preserve SOC stocks. The drainage conversion, or cultivation of peatlands should be avoided. Existing drains should be blocked to reduce erosion and maintain a shallow water table. Where possible, degraded peatlands should be restored.
- While there is no specific policy on soil at EU level, several related acts address the state of organic matter in soils. However, there are large uncertainties in measuring changes in soil carbon stocks, especially at plot level and over short time intervals. Regional assessments are even more complex.
- Some soils of the managed ecosystem contain a SOC pool, which is below their potential. Thus, such soils of the managed ecosystem are potentially a sink for C through adoption of appropriate land use and sustainable management practices.
- Several land management practices show promise in preserving or even increasing SOC levels

Specifically the Part 1 report presented:

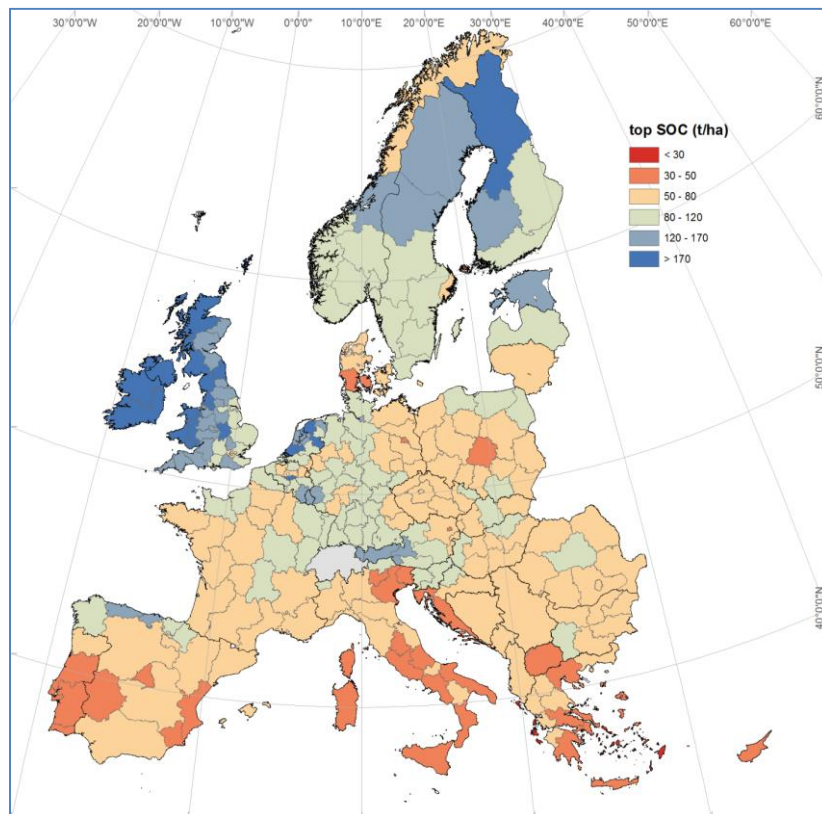
- **Maps of the extent of agricultural soils and associated SOC stocks**



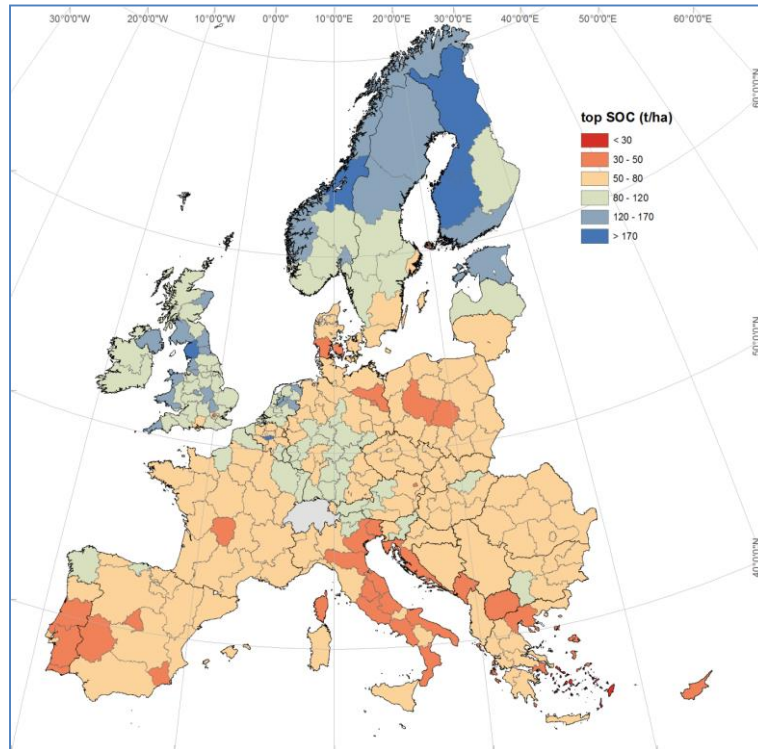
Agricultural land mask as defined by CORINE Land Cover 2006 based on arable, pasture and permanent crops classes.



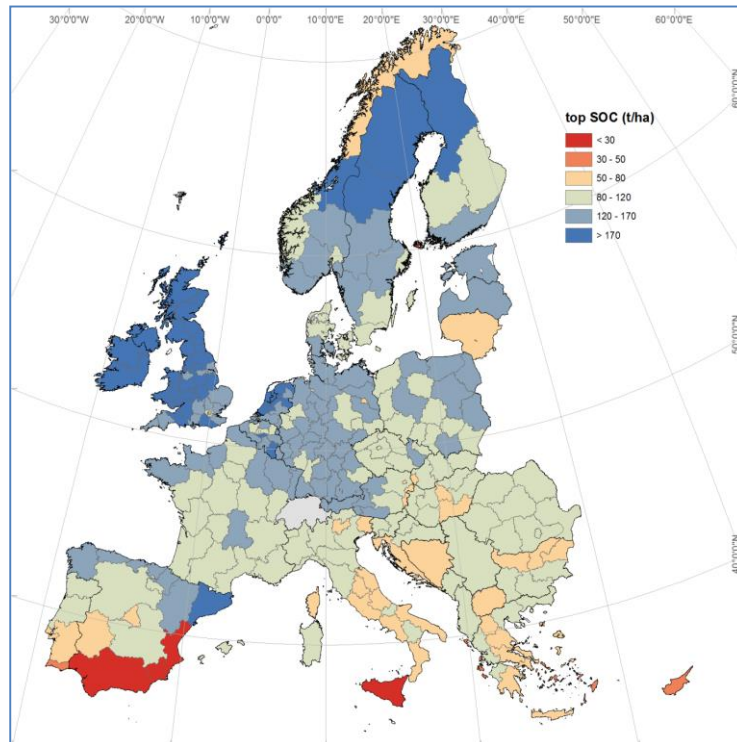
Map of disaggregated topsoil (0-30 cm) organic carbon concentration (t/ha) for all agricultural land uses simulated for 2010 land cover and climate conditions by the Century model.



Map of SOC stock (t/ha) for all agricultural land uses aggregated for NUTS2 regions simulated for 2010 land cover and climate conditions by the Century model.

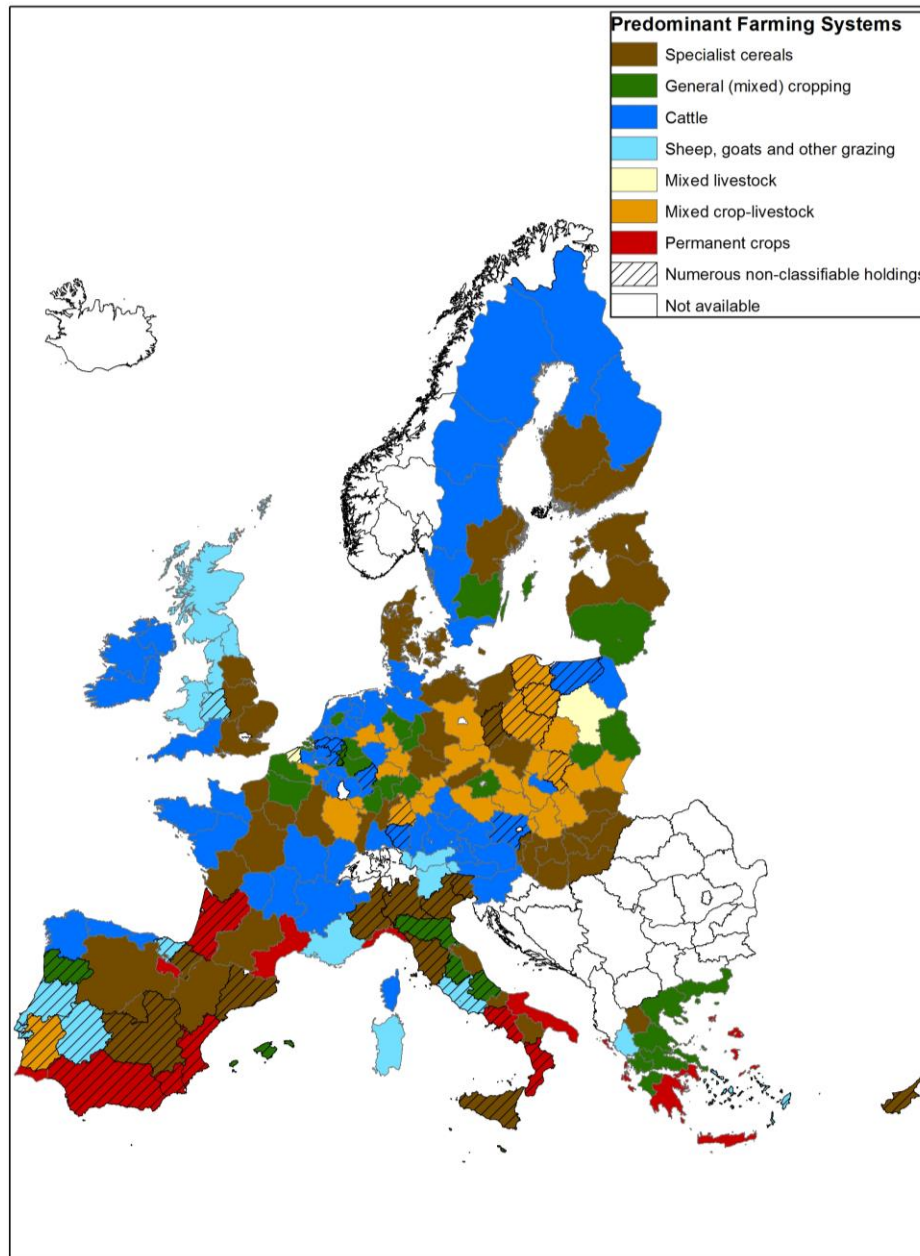


Map of SOC stock (t/ha) for arable land aggregated for NUTS2 regions (based on the Century simulation for 2010 land cover and climate conditions). Preliminary estimations predict arable land as storing around 8 Gt C.



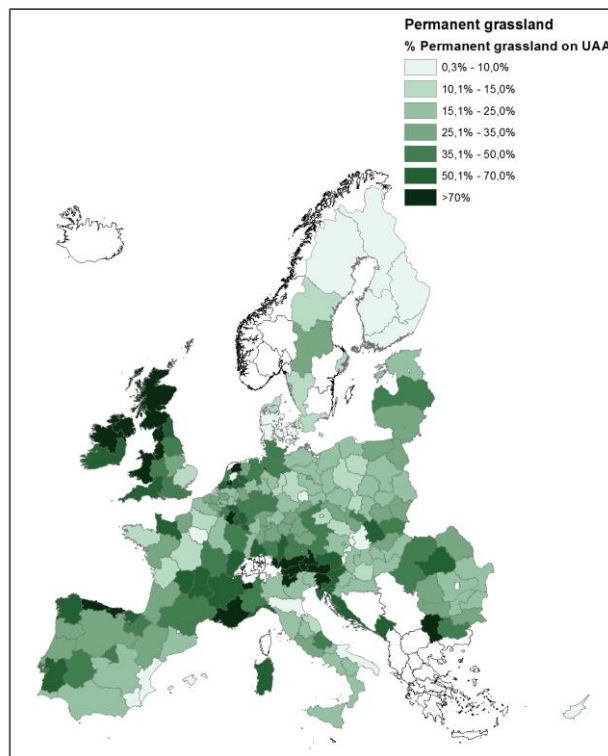
Map of SOC stock (t/ha) for pasture aggregated for NUTS2 regions (based on the Century simulation for 2010 land cover and climate conditions). Preliminary estimations predict arable land as storing around 12 Gt C.

- **NUTS2 level maps of current cropping and farming systems**

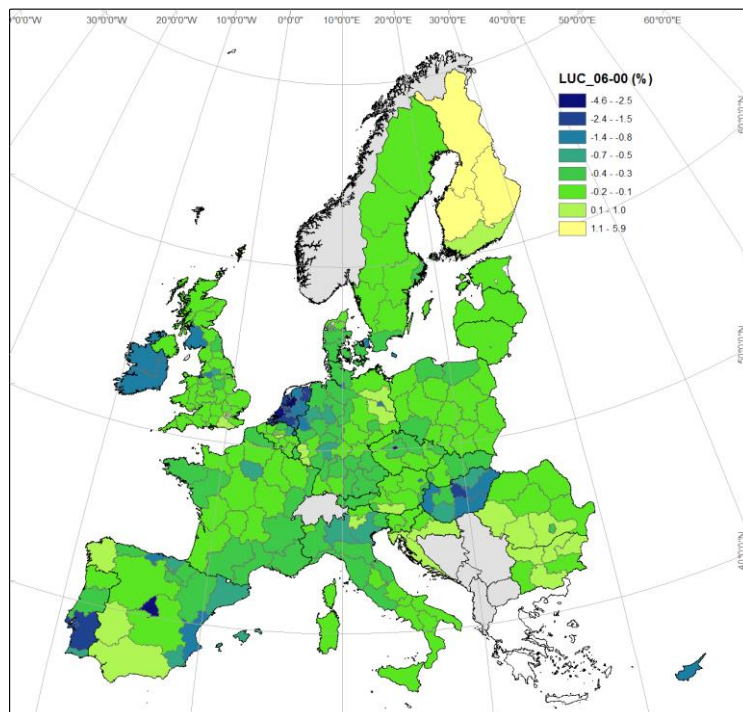


Map of predominant farming systems at NUTS-2 level based on a simplified classification of EU UAA 2002-2011. The maps shows that the most dominant farming systems are: specialist cereals, oilseed and protein crops (19%); cattle (17%); general field cropping + mixed cropping (12%); mixed crops-livestock (12%).

- Maps of current permanent grasslands and focus areas of land use change

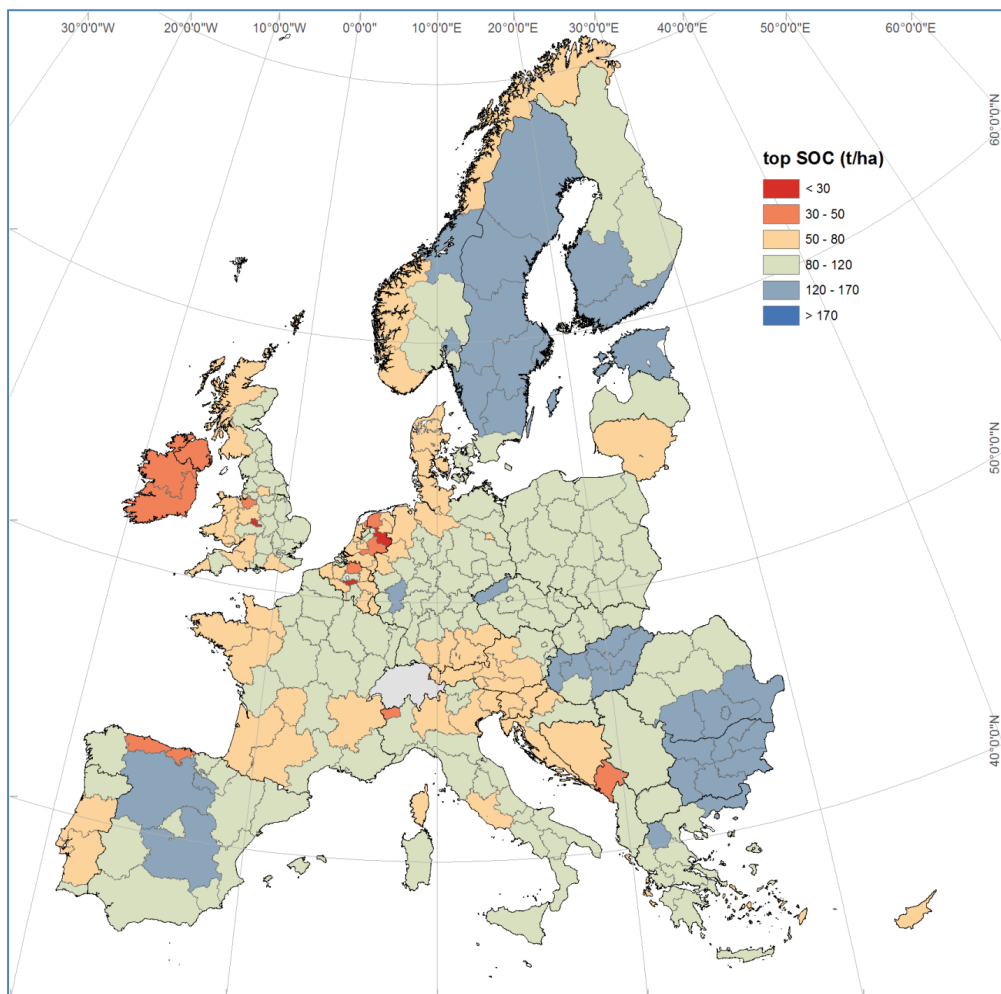


Distribution of permanent grasslands (pasture and natural grasslands) from CORINE Land Cover 2006.



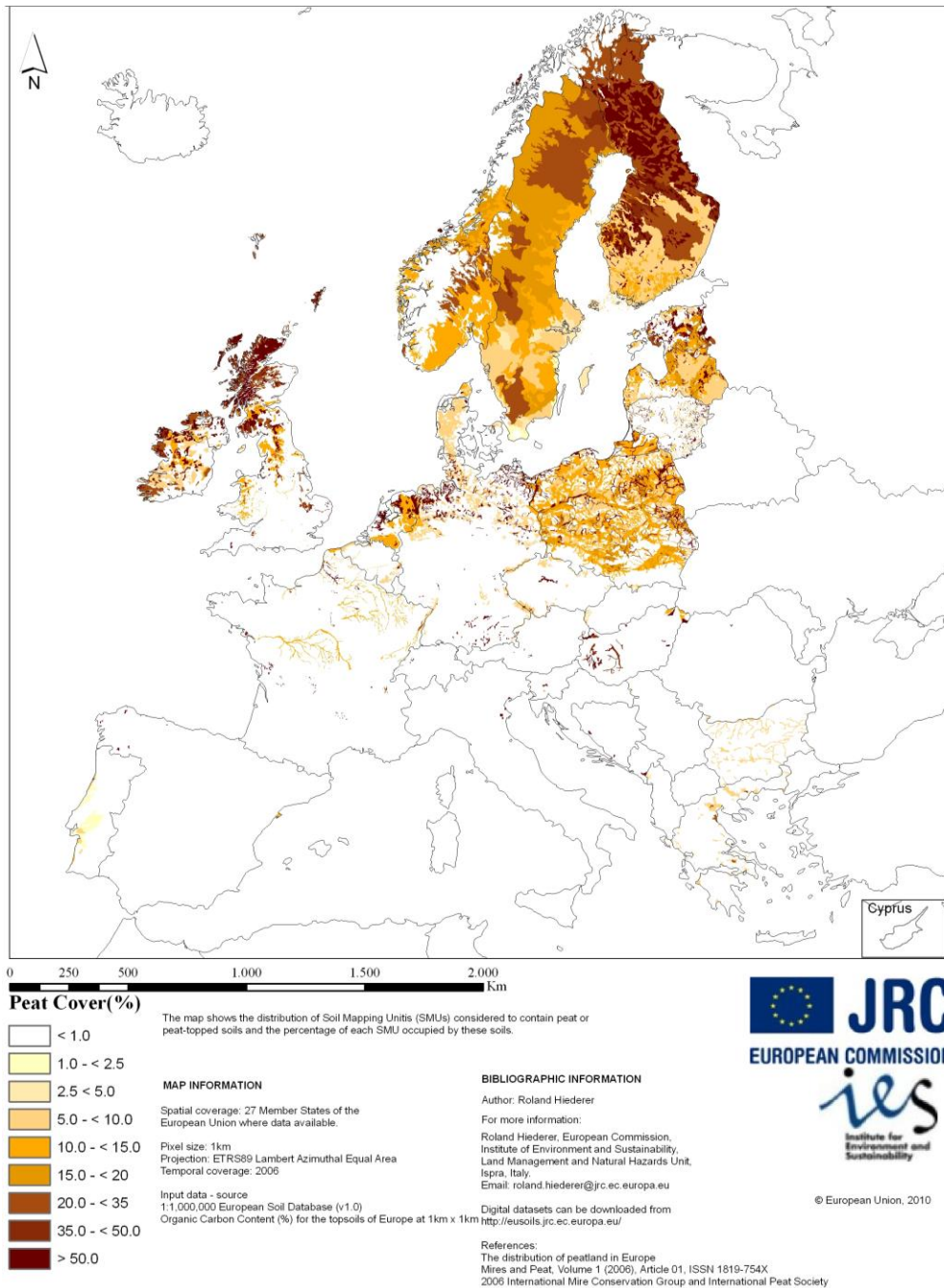
Net agricultural land use change (% of agricultural area) between 2006 and 2000. NUTS2 level for EU-28 (data for Greece are not available). Negative values indicate a loss, positive a gain of land classified as 'Agricultural areas' in the CLC. Maps were also produced to show changes in arable and pasture land cover.

- **Map of the current carbon sequestration potential in EU**



Map of potential natural SOC stock (t/ha), aggregated for NUTS2 regions. This map show the difference between the actual estimated SOC content for 2010 and a theoretical optimum condition for soil SOC storage where all soils have been converted to grassland (not N limited). Areas with low potential (e.g. Ireland, western France) already have soils that are already either at, or close to, their maximum potential. Blue areas denote areas that have the highest potential to increase SOC stock. This modelling exercise does not intended to identify the actual C sequestration technical potential for the EU, as the conversion of all the agricultural land to grassland is clearly unreliable. Instead, the identification of a maximum storage capacity for a purely biogeochemical point of view can help delineate areas where the actual SOC stock is far below this threshold. In this sense, the potential SOC stock values should be regarded as an index of potential soil storage capacity, which may indicate where alternative managements may be more effective. (Derived from the CENTURY model for 2010 baseline).

- **Map of the current carbon preservation potential in EU**



Part 2 of Task 1 reviewed the scientific literature on a variety of land management options that were deemed to have the potential to stabilise or enhance SOC levels and soil carbon stocks in relation to variations in soil characteristics and climatic conditions. The report also evaluated the negative aspects of mitigation (e.g. reduced C sequestration resulting from biomass use) and evaluated the possible constraints that inhibit the full application of mitigation options.

Specific potential mitigation practices covered **grassland management** (for example, improved grazing production, controlled grazing intensity, minimum grass coverage), **cropland management** (including crop variety and species management, crop rotations, cropping patterns, agroforestry, tillage practices), **nutrient management** (including both organic and inorganic amendments), **high technologies**, **water management** (including the restoration of peatlands) and **land restoration**.

There is no single option that if applied across the EU that would give a certain rate of soil carbon sequestration.

Analysis of the scientific literature indicates that:

- the maintenance of permanent grasslands has high potential to preserve SOC stocks from a biochemical potential (no consideration of market conditions) while the conversion of arable to grassland has a high sequestration potential from a biochemical potential (no consideration of market conditions).
- measures for controlled grazing intensity, maintaining a minimum grass coverage, nitrogen-fixing crops, crop rotations including specific species or varieties (cover crops, green manure and catch crops) and adopting longer rotation, terracing, reduced tillage, contour ploughing, organic amendments (e.g. compost, farmyard manure) and balanced fertilisation appear to have a high sequestration potential from a biochemical potential (no consideration of market conditions).
- management measures for improved grass production, perennial crop, improved fallow, compaction reduction and the restoration of degraded land appear to have a medium potential to increase SOC stocks (no consideration of market conditions).
- management measures for intercropping or mixed cropping, contour strip cropping, relay cropping, undersowing, mulching, weed management, stale seedbeds, buffer strips, conservation tillage, ridge tillage, crop residue management, alley cropping, silvopasture, boundary systems, wind breaks and liming appears to have some limited potential to preserve and increase SOC stocks (no consideration of market conditions). However, many

of these measures are often difficult to quantify due to a lack of supporting information and studies in the EU.

Increased removal of crop residues will most likely lead to a significant reduction in SOC stocks unless other organic material is added to compensate. There may also be secondary soil degradation consequences

The use of genetically modified crops, biochar, precision farming and irrigation appear to have some potential to enhance SOC stocks. However, data are lacking for effective assessments or scenario developments.

Several measures would benefit from being implemented in combination with other practices (e.g. crop residue and low tillage, increased cutting of grasslands with lay-based rotation, cover crops in arable rotation). Conservation agriculture, organic farming and integrated pest management systems lend themselves to such cohesive approaches.

While several practices have been shown to be theoretically effective at C sequestration, many lack robust assessments both geographically and over time. The issues raised in this report should be used to launch new studies to collect the missing information.

Many practices display pronounced secondary benefits ranging from improvements in soil, crop and environmental quality and water retention to the prevention of erosion and land degradation. Many show strong correlations with an enhancement in soil biodiversity.

3. Task 3: Assessment of different mitigation options

On the basis of the information presented in Task 1, a range of mitigation options were quantitatively assessed for their potential impacts on soil organic carbon stocks.

The options taken into consideration in the scientific literature have been assessed on a broad range of experiences, on the following criteria for the selection:

- a. Geographically representative
 - EU climate (cool mild climate): precipitation, temperature, in a temperate life zone.
 - Soil properties (texture, clay content, bulk density, OC content (no highly depleted OC soils))
 - Landscape position and land cover: arable land and grassland basing on CLC
- b. Positive SOC sequestration potential (i.e. value in stocks referring to a specific duration, preferably LTEs), even though also negative has been inserted to let understand the negative effect on a specific practice (e.g. drainage of peatland)

The mitigation options showing a high potential estimates in SOC sequestration or/and preservation have been later assessed on their relation with:

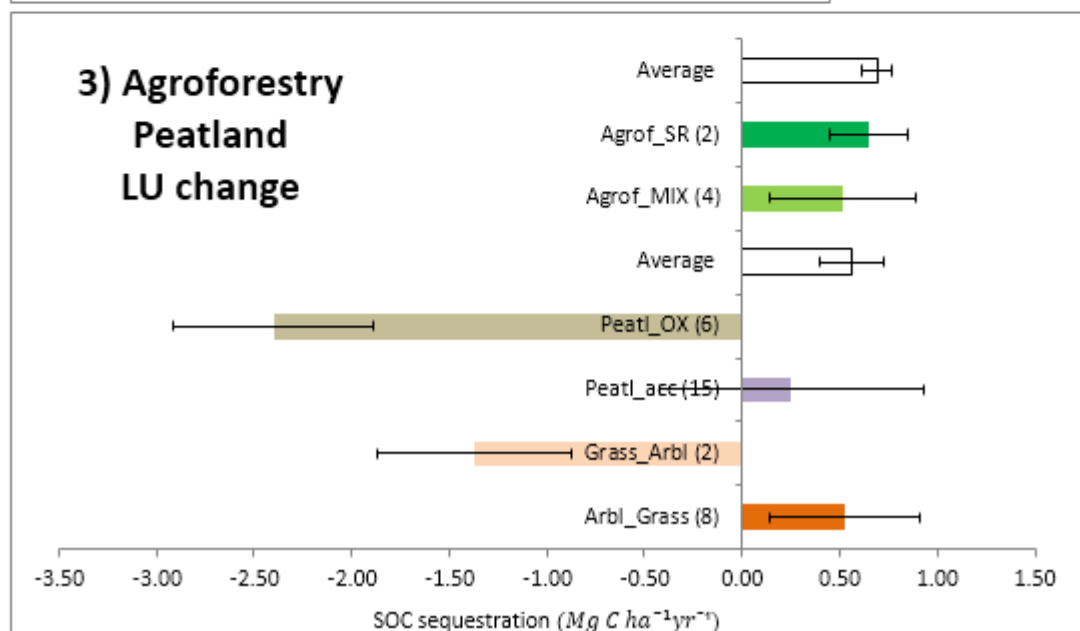
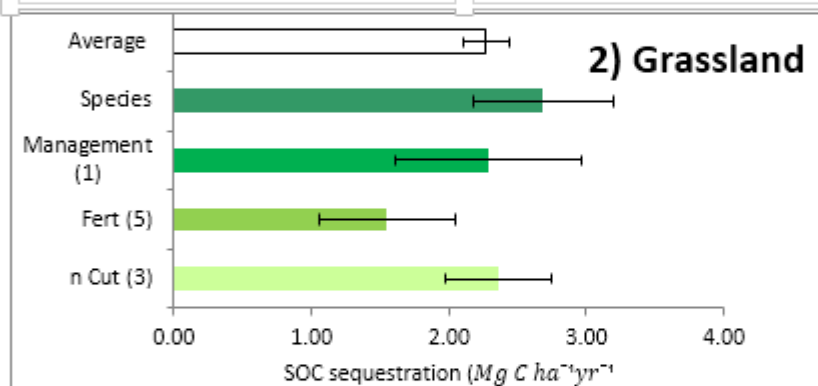
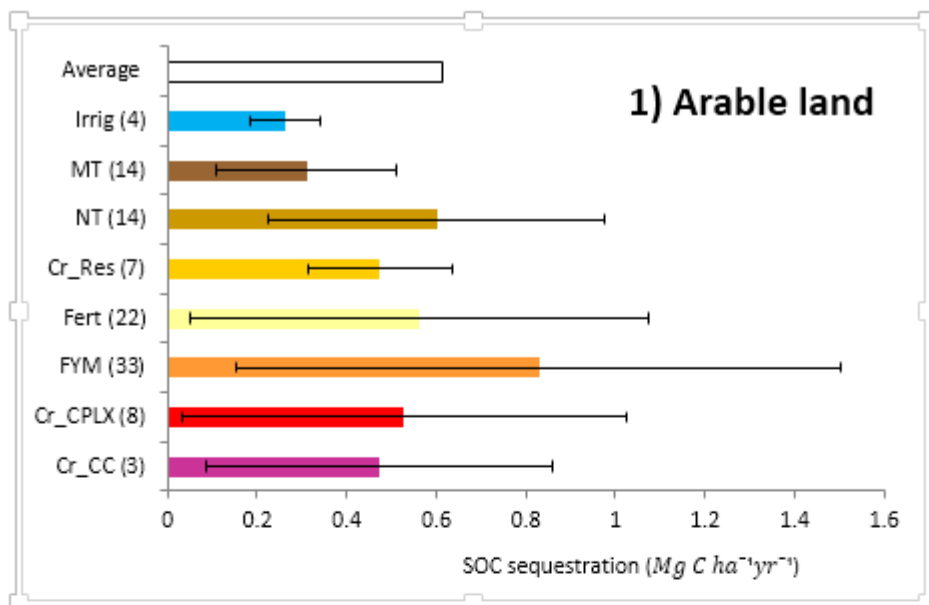
- c. Datasets availability at pan-European scale (referring to Task 1 Part 1)
 - Soil data derived from the European Soil Database-ESDB, available at the European Soil Data Centre (ESDAC). The properties considered for the top-soil layer (0–30 cm) included soil texture, bulk density, pH, drainage class and rock content at 1 km × 1 km grid resolution.
 - Land use and land management practices: Corine Land Cover (<http://www.eea.europa.eu>), EUROSTAT (<http://epp.eurostat.ec.europa.eu>) and the AFOLU Data Center (<http://afoludata.jrc.ec.europa.eu>).
 - Climatic datasets for the period 1901–2000 and projected for 2001–2100 were provided by the Tyndall Centre.. The TYN SC 1.0 dataset covers the whole of Europe with a grid of 10' × 10'.
- d. Modelling feasibility within the CENTURY framework, specifically:
 - High mechanistic representation of the technique
 - Management factor can be represented

Only if all these criteria are fulfilled, then the mitigation option could be selected to be simulated.

The SOC sequestration data collected were assessed further (where possible) on the basis of a very broad meta-analysis. Results show that:

1. Arable land related practices: the graphic shows that all the practices selected range between 0.25 and 0.85 Mg C ha⁻¹ yr⁻¹.
2. Grassland related practices: the graphic shows that all the practices selected range between 1.5 and 2.85 Mg C ha⁻¹ yr⁻¹.

3. Agroforestry/peatland/Land Use change related practices: the graphic shows different attitudes in relation to the practices selected. Agroforestry mixed and short rotations give positive values around $0.5-0.6 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$. The oxidation of peatland and the conversion from grassland to arable give negative values. Peatland accumulation and conversion from arable land to grassland gives positive ranges.



All the labels show a number in brackets. This value refers to the number of studies assessed as effective to be accounted in this meta-analysis. Many studies have been not taken into account because of they were based on short term experiment or were lacking clear comparison or information.

Every bar shows the standard deviation of the values. All the bars are characterised by a broad variability due to the relative small number of studies and most studies have unique characteristics (i.e. soil type, location, and climate) that give rise to different SOC sequestration rates.

Due to this dependency of the potential of mitigation to the geographical condition of the study there is no single optimum option that, if applied across the EU, could give an absolute certain rate of SOC sequestration. For this reason is necessary to categorised and choose a statistical approach in the selection and assessment of the mitigation practices. For each category there a total average is presented (white bar).

In general, the potential SOC sequestration of the selected promising mitigation options range from between 0.2 to 1 Mg C ha⁻¹ yr⁻¹.

Some options (e.g. minimum tillage) give higher SOC sequestration potential but were not considered further due to a lack of supporting data for modelling.

As a result, the following management practices were selected for the modelling exercise:

Grassland management and preservation

1. Conversion from arable to grassland (reduction of the area dedicated to arable marketable crops)
2. Conversion from grassland to arable
3. Different regimes of grass biomass removal

Cropland management

4. Residue management: total removal and incorporation of straw with respect to BAU (assuming a 50% of crop residue incorporation);
5. Reduced tillage: substitution of the mouldboard plough with a secondary more superficial tillage.
 - o Minimum tillage + 100% residue incorporation
6. Manure: reduction of application rate with respect the BAU
Variations in crop rotations:
7. Two-years fodder crops within the BAU rotation in arable areas
8. Cover crops intercalated among the main crops and incorporated into soil (green manure)

Agroforestry

9. Alley cropping system growing trees (poplar) and crop (wheat) on the same field (inter-cropping system).
10. Conversion of arable rotation to a medium-term (20 yr) coppice poplar rotation with a 5-yr cutting cycle.

Sustainable arable systems

11. Based on previous results, this scenario wanted to assess the most sustainable SOC sequestration practices among those simulated in the cropland management. Practically, the

management having the highest SOC gain is identified at different geographical and time scale.

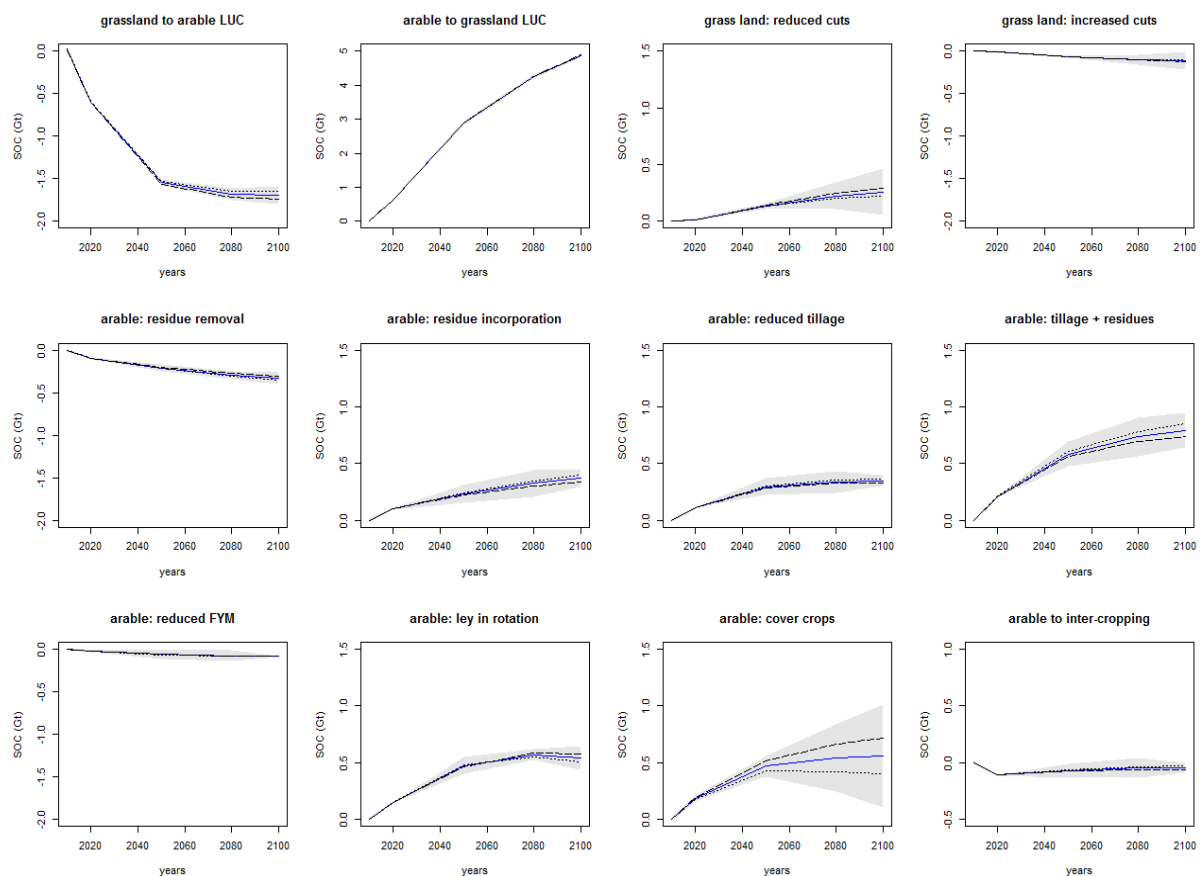
4. Task 4: Scenarios to assess the impacts of different mitigation options across the EU

Based on the inputs from Task 3, two linked sub-tasks were carried out.

Task 4a assessed the geographic distribution and temporal evolution of SOC levels in agricultural soils as a result of the selected mitigation options. Various mitigation options were simulated to assess for their potential impacts on soil organic carbon stocks in the agricultural soils of the EU. That was made possible through the development of a simulation platform that linked a biogeochemical model (CENTURY) with geographical and numerical databases.

It was therefore possible to make a new estimation of soil organic carbon (SOC) stock in agricultural soils at pan-EU level and a comprehensive set of simulated management sequestration practices.

Cumulated SOC change (Gt of C) at EU level, related to the full application of the simulated alternative management practices have been presented in the report of Task 4a (see below). The values are projected to the year 2100 using two climatic scenarios, the variability (grey area) associated to the climate data has also been calculated.

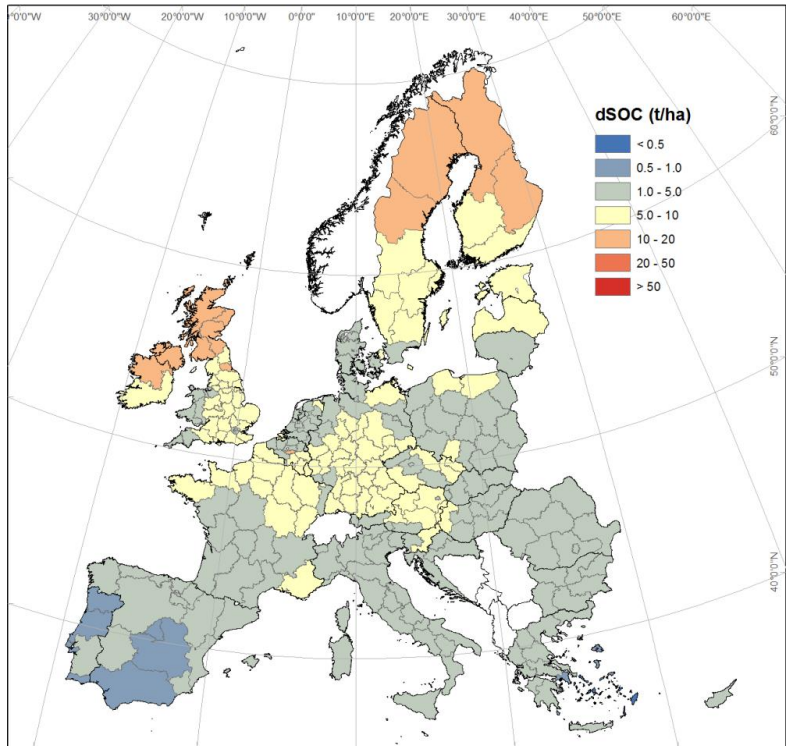


Analysis of the SOC stock predictions show that:

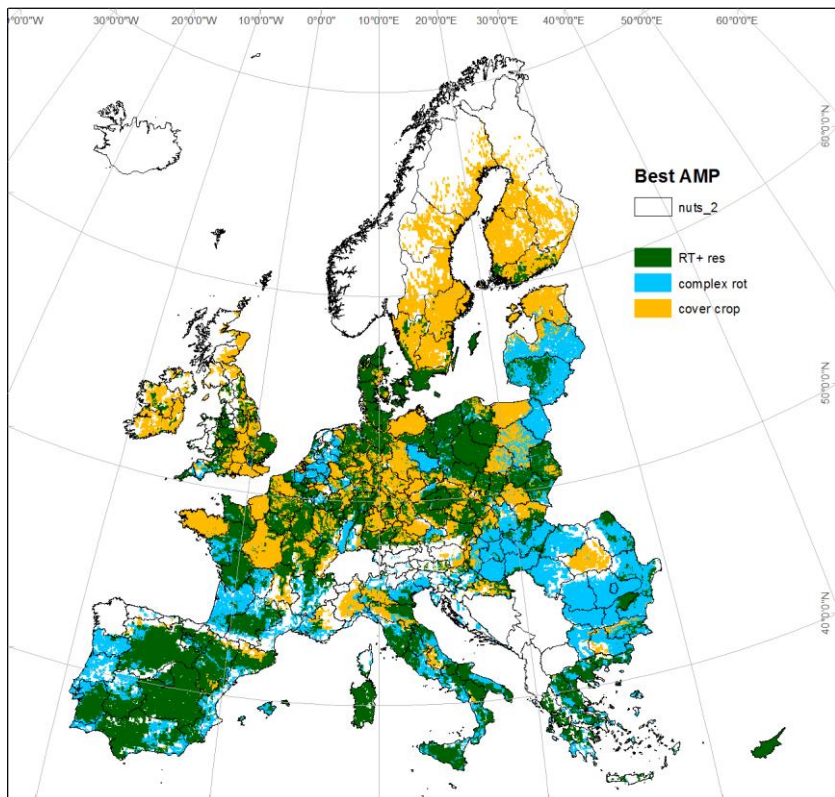
- LUC scenarios had the greatest impact in term of SOC change compared to alternative managements under the same land use;
- the conversion of grassland to arable land can rapidly lead to consistent SOC losses, ranging from 0.5 to 1.5 Gt in the time period 2020 - 2050;
- the conversion of arable land to grassland led to the most rapid and absolute SOC gain.
- different regimes of grass biomass removal had a marginal effect at 2020;
- the simulated incorporation of straw residues were comparable to the reduce tillage scenario in term of SOC sequestered; moreover, the combination of these practices allowed the (potential) accumulation of 0.21 and 0.58 Gt of C at 2020 and 2050, respectively;
- the 20% reduction of manure rate application was estimated to have low impact on SOC change in arable systems;
- managements based on increasing complexity of crop rotation showed higher potential than residues management and reduced tillage;
- the SOC gain with the cover crop scenario was 0.18 and 0.47 Gt of C at 2020 and 2050, respectively; however the uncertainty was particularly high since 2050;
- inter-cropping systems showed a small negative SOC balance in the short term (2020) and a tendency to neutrality thereafter. The overall C budget is on average positive when considering the C allocated in the wood biomass.
- an additional scenario was run to evaluate the effect of substituting root crops (sugar beet and potato) with grain pulses. Overall, the projected SOC change was close to zero (Annex 3) although small losses in northern parts of the EU were compensated by gains in the south and east. However, this scenario should be considered explorative as further model calibration may be necessary to simulate the high soil disturbance related to the management of root crops.
- on average, the sink soil capacity was increasing at least until the next 50 years;
- the variability of the estimations was predicted to be higher in the second half of century.

In addition, this task produced maps showing the distribution patterns of SOC stocks under targeted mitigation options at NUTS 2 level. An example for cover crops is presented below.

Agricultural systems subjected to a change in management or land use require several years to reach a new SOC equilibrium. The dynamics are often not linear, thereafter a selected management which shows high accumulation rate in the short-term, may have a lower effect in the medium, long-term compared to alternative systems. A scenario was developed to assess the most sustainable SOC sequestration practices among those simulated under *cropland management*, identifying the BMPs having the highest SOC gain at different geographical and time scale. The map is presented on the following page.



Aggregated values (at NUTS2) of soil organic carbon stock change (t/ha) under the cover crop scenario for 2050.



Best management practice in sequestering SOC among those simulated in the arable system in 2020 and 2050. **RT+ res**= reduced tillage + residues incorporation; **complex rot.** = introduction of a 2 years fodder crops in BAU rotation; **cover crop** = introduction of cover crops in BAU rotation.

Task 4b aimed to assess the effects of selected management measures on existing agricultural production systems in terms of changes in crop production.

Task 4b simulates the impact of different agro-management practices, which could be beneficial for capturing and preserving of soil organic carbon, on productivity and production of main crops in the EU as well as on grassland in one MS (France). The Bio-physical Model Applications (BioMA) modelling platform has been used to perform simulations of crop and grassland growth and development with a focus on water management in agricultural soils.

Firstly, three irrigation strategies were examined for maize production with different production potentials, namely full, deficit and conventional irrigation. An increased production as a result of irrigation could decrease the pressure on using other land for crop production as well as reducing the need to apply fertilisers. Furthermore, a higher amount of biomass would remain in the soil, microbiological processes of decomposition would be more intensive and it is expected that soil organic carbon content would increase.

Secondly, an analysis of the set-aside measure, in which a certain percentage of arable land area is taken out of cropping, was performed to assess its impact on crop productivity and production. The impact on productivity and production of the set aside areas can be considered as being closely related to what would be the impact of establishing Ecological Focus Areas. Soil carbon increases have been reported in literature for managed and unmanaged conversions of cultivated land. Several potential environmental side effects of set-aside can be identified. Loss of production due to set-aside can entail leakage, inducing the need to replace this production elsewhere.

In addition to these two measures analysed at European level, the impact of various tillage practices on crop yield within a specified crop rotation pattern were simulated using a case study of Romania. Simulations were performed in order to assess the impact of different combinations of tillage practices and irrigation on production of three crops within the rotation pattern in Romania: winter wheat, maize and sunflower. A production increase would lead to higher carbon accumulation in soils. Increased production on tilled and irrigated plots may lead to reduced pressure on using other land and reduce the amount of fertilizers.

Furthermore, the impact of setting aside arable land was examined in a second case study that looked at the conversion of arable land to grasslands for France and the impact of such a conversion on crop productivity. The simulations of grassland were undertaken in order to assess the impact of the conversion of arable land to temporary grassland by setting aside the least productive wheat areas in France.

The results of the study showed that grain maize productivity and production on EU-28 level increased by 34 % under the full and deficit irrigation strategies, whereas a 29 % increase was observed under the conventional irrigation strategy. The increase in northern Europe is less pronounced than in southern and eastern parts of the EU. Optimizing the timing of irrigation by using deficit irrigation resulted in similar yields than using the full irrigation strategy, but significant amount of water could be saved.

Results of the set-aside analysis show an increased productivity for winter wheat and grain maize in Europe, but a simultaneously decreased production. If 10% of arable land with least productive soils were set aside, the productivity of winter wheat on EU-28 level would increase for 1,2%, whereas the production would decrease for 8,9%. Under the same conditions, the productivity of grain maize would increase for 1,4%, whereas the production would decrease for 8,8%. The increase was particularly pronounced for winter wheat and grain maize in the central and western Mediterranean region, in Hungary and in Poland. The overall crop production is reduced at a lower rate than the reduction of the arable land area due to the productivity increase.

The simulation of different tillage practices have shown that tillage has an important effect on crop production and productivity. The tillage impact on yield was most significant over areas where

rainfall is not sufficient to avoid drought stress in the most sensitive period and for drought-sensitive crops, i.e. grain maize over summer.

The analysis of the conversion of arable land to grassland showed a decreasing productivity of the grasslands, mainly due to their extension to less fertile soils, whereas the productivity of remaining wheat growing area is increasing, as the least productive wheat growing areas are being taken out of wheat production for conversion.

- **Example of the mapping of impact on production for selected mitigation measures**

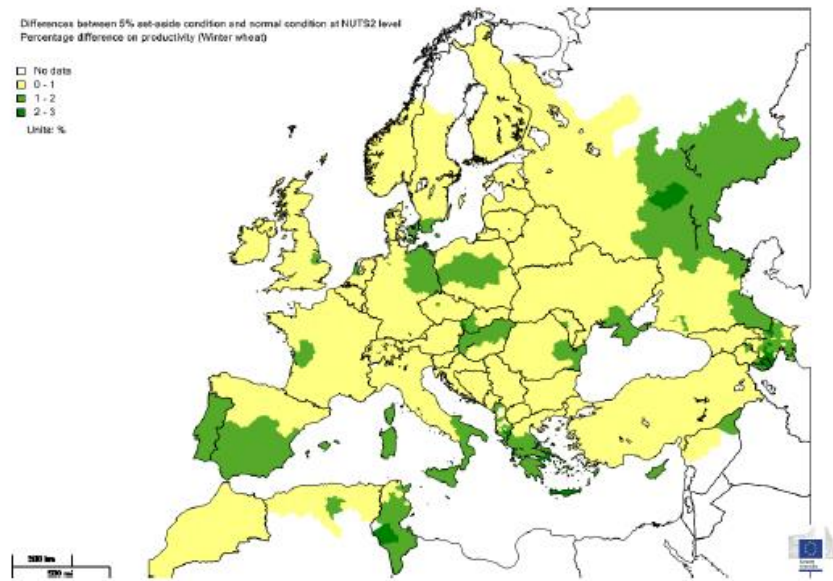


Figure 19: Relative difference of winter wheat productivity between 5% set aside and normal conditions at NUTS2 level over whole Europe.

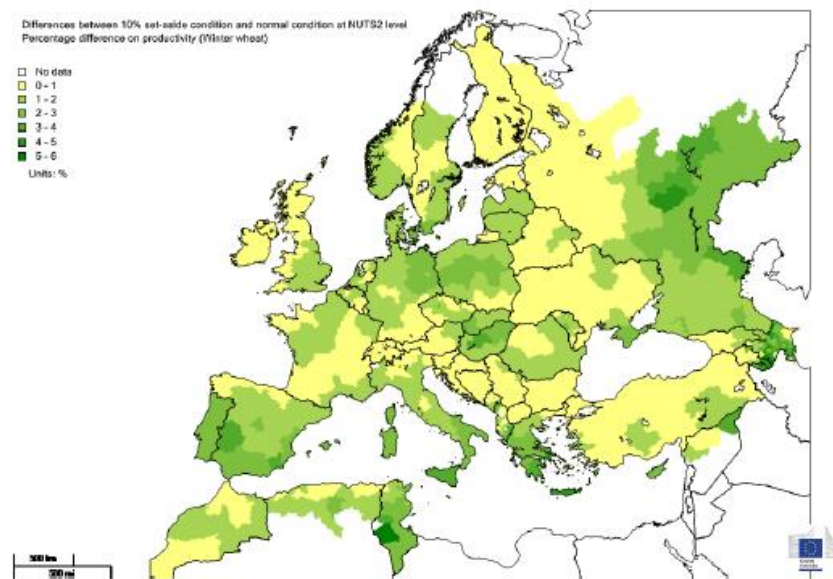


Figure 20: Relative difference of winter wheat productivity between 10% set aside and normal conditions at NUTS2 level over whole Europe.

Nevertheless, the present analysis was limited largely to the impact of agro-management strategies on crop yield and production through the influence of soil water on crop growth and development. In the future, also the nitrogen cycle, which plays important role during the growth and development of plants, should be simulated. The nitrogen cycle has important impact also on soil organic carbon, since the increase in fresh organic matter sources can stimulate the decomposition of 'old' soil organic matter. The impact of different tillage practices (e.g. no-tillage or zero-tillage), where the moldboard plow is replaced with a secondary, more superficial tillage practice, should be analysed as well. Zero tillage does not disturb soil through tillage and increases the amount of water and organic matter in the soil. It can also decrease erosion, reduce production costs, decrease the consumption of fossil fuels,

and improve soil structure. Changes in crop rotation patterns could also have an impact on crop yield, especially when including the impact of crop residue incorporation on soil organic matter.

The impact of rotation and agro-management practices on crop productivity and production has a very high spatial variability, depending on the soil type, climate conditions, nutrition applications, irrigation infrastructure, local tillage practices and numerous economic factors. Integrating all factors into continental-scale simulations is highly demanding in terms of spatially resolved input data, model adaptation, and computational time. Addressing these questions simultaneously at continental scale rather than in dedicated case studies as performed for the CARPESE project will require further refinement and adaptation of existing BioMA components. Furthermore, limited data availability on continental scale hampers further model refinement activities. Complexity will increase further when including aspects of climate change impacts and adaptation in such an analysis due to a considerable increase in data handling and uncertainty.

5. Task 5: Evaluation of the economic, financial and secondary effects

This task aimed to evaluate the financial, economic and secondary effects of the various mitigations measures on existing agricultural systems.

A priori, the intensity of the effects on the introduction of mitigation measures on the farming systems will depend on how these systems have already been embedded in the current CAP (e.g. through cross compliance and rural development measures) and how important the changes in the current farming practices will be. Greening measures and changes to the GAEC system (two new soil related GAECs) as proposed by the Commission for the post-2013 period will also be considered. However, the effectiveness of these measures in terms of carbon preservation/sequestration, and consequently the cost effectiveness of these measures in comparison with other, non-agricultural mitigation measures have not yet been sufficiently elaborated. The assessment in this study should go beyond and elaborate costs and cost effectiveness of mitigation measures, including those potentially supported under rural development.

Effects also depend on the mitigation effort required to be undertaken in agriculture. Different scenarios for mitigation targets should be used, which, where possible, should be in line with the Roadmap for moving to a low carbon economy in 2050 (COM(2011) 112 final and SEC(2011) 288 final), which requires increased mitigation efforts over the coming decades. This means that scenarios will differ with respect to the mitigation effect to be achieved, including BAU, intermediate scenarios and a scenario assuming the full implementation of recommended measures. Scenarios will be differentiated by the assumed carbon price, which determines the cost effectiveness of measures, or by pre-defined mitigation targets to be achieved in relation to cropland and grassland management.

Three sub-tasks were defined.

Task 5a was to investigate the financial aspects of the selected mitigation measures through cost estimates associated with the implementation of the different practices in relation to cropping systems together with an assessment of the cost-effectiveness of the mitigation potential per ha, the area potentially involved and a comparison with non-agricultural mitigation measures.

Specifically this task produced:

- An assessment of cost of implementation of mitigation measures
- An assessment of cost-efficiency of mitigation measures and compared to non-agricultural mitigation measures. On the basis of available data
- An assessment of mitigation measures present in the greening of the CAP and GAEC requirements.

As a component of cross compliance, farmers are obliged to keep the agricultural land in Good Agricultural and Environmental Condition (GAEC) by complying with a number of minimum requirements in issues such as the prevention of soil erosion, the conservation of soil organic matter and structure, a minimum level of maintenance and the protection and management of water. It must be noted that largely GAEC standards are defined at the level of a Member State and shall be implemented in the same way on the whole territory. Regional variations are only rarely applied, sometimes in Member States with regional autonomies like Germany and Italy. However, it happens that some requirements are compulsory only for a territory with a specific issue or characteristic (e.g. land prone to erosion, parcels with slope), or only for a specific land use (e.g. arable land, grassland, fallow land). The recent reform of the CAP has introduced the so-called “greening” of direct payments, aimed at supporting farmers for agricultural practices beneficial for the climate and the environment. It consists of three practices related to crop diversification, permanent grassland and the Ecological Focus Area (EFA) whose implementation will start in 2015. Currently, a lack of detail on the implementation does not allow a proper analysis of the practices that will constitute the greening. Besides that, some farming practices already present in GAEC will merge in the greening in the future (e.g. crop diversification). The analysis presented in the CAPRESE project is therefore focussed only on GAEC with some reference on the greening measures when needed.

For its nature, GAEC plays no role in promoting land use changes that increase the soil C content (such as conversion of arable land into grassland) and only a limited role in preventing land use changes which decrease the soil C content (conversion of grassland to cropland, drainage of land). At this regard, the requirement known as permanent pasture ratio (art. 6 (2) of Council Regulation EC No 73/2009) is the only one imposing restrictions on land use changes. Anyway it has a limited role as it is generally applied at national level with little possibilities of preventing the ploughing up of permanent pasture at farm level. With the reform for the CAP after 2013, the provision referring to the permanent pasture ratio has been removed from GAEC (only a transitional period of application remains) and has become a “greening” practice with some changes. The definition of permanent pasture has been changed into permanent grassland in order to include in this land use also species such as shrubs and/or trees suitable for grazing provided that the grasses and other herbaceous forage remain predominant. The ratio of the land under permanent grassland in relation to the total agricultural should not decrease by more than 5% compared to a reference ratio to be established by Member States (it was 10% in the past permanent pasture ratio). Besides that, the greening measure on permanent grassland establishes that farmers shall not convert and not plough permanent grassland situated in environmentally sensitive areas covered by Directives 92/43/EEC or 2009/147/EC and in other sensitive areas not covered by the two directives but designated by Member States; these latter areas may also include permanent grasslands on carbon rich soils. This represents a clear restriction of land use changes with a positive mitigation effect, but the extent of this measure on the preservation of C soil levels cannot be estimated at this moment as areas where to apply this provision have not been established by the Member States yet. In this framework, Member States would positively contribute to maintaining soil carbon stocks if this measure were applied widely to peat land and other carbon rich soils.

Much broader is the contribution of GAEC in defining management practices with positive effects on Carbon soil stock. The same practices generally fulfil other objectives such as the prevention of soil erosion and the improvement of soil structure and therefore have been defined in the framework of GAEC.

For **grassland**, mitigation management mainly refer to standards related to avoid overgrazing and undergrazing. These practices are part of compulsory requirements in many regions where the presence of permanent pasture is high. Even if the analysis at NUTS2 has some limitations as it does not allow to determine precisely the effects at farm level, in these areas the introduction of some of the suggested mitigations options should not be perceived as new and should not have a big impact on the grassland farming systems. However there are areas with a high percentage of permanent grassland where none of these requirements have already been established by the Member States. These will be the areas where the introduction of the suggested mitigations options may have the highest impact.

For **cropland**, many GAEC requirements contain mitigation options and generally fulfil goals that go beyond soil carbon stock improvement. Some GAEC standards for which some requirements have been designed will be no more included in the new GAEC framework (such as the measures against soil compaction or for crop rotation) but some of the defined requirements may be maintained if they fit into one of the remaining standards. Among the management practices, establishing a cover crop is an obligation that can be found in all Member States, even if the conditions for which the cover crop is compulsory, the type of cover crop and the period when it shall be maintained on the field can vary in the Member States. This management option will not represent a wide change in farming practices as in most cases is already implemented by the farmers in the framework of GAEC.

Optional GAEC standards on crop rotation have been implemented both as a restriction in the cultivation of some crops for some consecutive years and as an obligation to cultivate different crops in the holding in a given year (crop diversification). The latter will be part of a greening practice in the next programming period, but within a framework established by the Regulation and generally different than the ones already implemented in some Member States for GAEC. It must be highlighted that even if the measure on crop diversification does not impose a crop rotation, the need of cultivation of different crops in the holding will create the condition for a rotation of the crops.

Tillage related practices are not present in GAEC except for contour farming which, as a measure to prevent erosion, is compulsory in some Member States at least for agricultural land above a certain slope or prone to erosion. Agroforestry can be linked to the GAEC standard on the retention of landscape feature, but this GAEC cannot be considered as very significant for the introduction of agroforestry techniques as it is limited to the non-removal of landscape elements already present (and sometimes only for elements listed as environmentally relevant) and it does not stimulate new planting. However re-establishing landscape features may become a need with the introduction of the greening practice of the Ecological Focus Area.

It is widely accepted, and extensively described in other deliverables of the CAPRESE project, that the effect of these practices on carbon soil stocks depends on local conditions of the climate and soil type. The potential for increasing the SOM in soil is higher in humid than in dry climate and therefore also the content that can be determined as a target may differ according to the climate region. GAEC standards are defined in relation to local conditions and can vary not only among Member States, but, within the same country, some requirements can be compulsory only for some farms or some pieces of land. This does not allow calculating figures on how much land is affected by one restriction nor how many farmers have in practice to deal with it. Anyway it is evident that, as it is demonstrated in other surveys carried out by the JRC (e.g. the low-carbon farming project), cross compliance have increased farmers awareness in environmentally-friendly practices. What it is not so apparent is that some of these farming practices contribute also to climate change mitigation.

It would also be useful to estimate the comparative effectiveness of existing GAEC practices, as well as their relative ease of implementation. It might also be helpful to assess which of them provide the best return for money.

However, a complete assessment of the relative merit of the various measures in terms of carbon preservation and sequestration is beyond the scope of this project, as it would require further ad-hoc research. The level of uncertainty is large, as can be seen in the academic literature and has been shown elsewhere in this project deliverables, too. The effects of the measures are essentially local. All GAEC practices show a different level of effectiveness in different regions. Moreover, while the effects of most practices are generally positive, there is also evidence of less positive or less certain effect.

Finally, there is little specific comparative economic assessment that would provide indications of their “value-for-money” relative merit. Only a few, partial economic assessments exist where a comparison of cost of implementation is performed for practices that are classified more broadly into “agronomy”, including crop rotations with perennial crops and cover crops along with other practices, or combining reduced tillage and residue management. These studies cannot be directly translated in a way as to provide assessments for the GAEC practices as described in this report.

Recent literature reviewing knowledge of greenhouse gases mitigation potential of agricultural practices reveal very large uncertainties. An additional difficulty is that studies generally address agricultural practices classified in various ways, but no study has specifically evaluated the comparative merits of the standard requirements of the GAEC.

Further research is needed not only to assess distinctive GAEC practices in specific local conditions but also management practices that will be introduced within the framework of the greening measures. Greening practices, such as EFA, give farmers some options to identify which management practices or land use (fallow land, landscape features etc.) to choose and on which land. Research should address the need of identifying the areas where the implementation of these management practices will have the best results in order to promote them among farmers situated in the most prone areas or, within the same holding, help the farmer to select the areas where these practices can have the most efficient return.

Tools provided by precision farming could help in optimising the implementation of management practices at farm level taking into account the effects of soil properties and of the weather, in developing management plans and adjusting them in the years as well as in gathering information at parcels through sensors. Further investigation is needed to identify how the use of precision farming can be widespread and a good level of effective results can be achieved.

All these potential fields of research open the issue of the analysis and research scales. NUTS 2 level seems to be too coarse and a need to move to local or even farm level is emerging. This will imply that adequate data shall be provided and collected at this scale.

Task 5b investigated the economic impact of selected mitigation measures in terms of changes in commodity market and the induced modification of farmers' income based on changes in agricultural production patterns. This task evaluated the scenario related to an increase in grassland in the baseline (year 2020) of 5% at NUTS2 level and the assessment of the economic impact of implementation of the above mentioned scenario named CAPRESE.

The increase in grassland area can be achieved either by transforming arable land or other type of land. The main reason for setting the target at NUTS2 level and not setting flat target at farm type level is derived from the fact that imposing it at each farm type (FT) can be too costly or not "fair" for some types of farms as well as there is no policy rationale behind it. It is assumed that different FT will find the best economically feasible solution within the region which depends on the dual value of the restriction associated to the increase of the level of grassland.

Simulations were done for the year 2020 while the base year of CAPRI model version used for analysis is 2008. The CAPRI baseline incorporates the AGLINK-COSIMO DG-AGRI baseline and it incorporates the CAP not considering the CAP Post-2013 Reform.

An imposed target to increase grassland by 5% at NUTS2 level increases the total utilized agricultural area at EU27 level by 0.4% while arable land decreases by 1.7%. For 8 countries - Denmark, Germany, Finland, Czech Republic, Hungary, Lithuania, Poland and Cyprus, there can be expected transformation only from arable land to grassland, and almost all the countries (with exception of Austria and Slovenia) would give up mainly arable farming instead of involving more new areas for agricultural use. At farm type level sharing of efforts for reaching the target set at NUTS2 level leads to different land use structure at different specialization of farms. Specialist cereals and oilseed, general field cropping, various permanent crop and granivores farming are expected to increase their grassland areas by more than 6%, while horticulture, dairying and cattle rearing farms increase by less than 5%.

Since forcing the increase of grassland as a result of transformation of other type of land, in CAPRESE scenario there can be expected a reduced supply of most of agricultural products. In terms of quantity the decrease for is less than 1% for all the sectors facing decline, while for beef and sheep meat slight increase can be foreseen with raw milk production remaining unchanged. Transformation of arable land is assumed to be performed starting from less productive areas, so there can be expected increased average yield compensating part of potentially lost production. At the same time yield per used for livestock production grassland area is decreasing as the command allow to enter into market less productive livestock farms. Changed conditions for products' supply will results in changes for producer prices on EU market. For all crop production prices due to drop in supply goes up while beef and sheep can expect slight price decrease less than by 1%.

The combination of price on yield change will influence the farms income. The highest increase by 1.2% is expected for cereals and oilseeds farms while granivores' specialization might face decrease by -2.6% in CAPRESE scenario compared to baseline. There is no significant effect on agricultural income per ha (decrease by 0.06% compared to the baseline). However, there is heterogeneity in the effects at Member States/NUTS2 level. Overall EU-12 countries are increasing agricultural income (0.61%) while EU-15 is decreasing (-0.23%).

Task 5c evaluated the possible secondary effects of selected mitigation measures in terms of potential offsets from non-CO₂ GHG emissions and carbon leakage. Due to a lack of technical capacity within the JRC, the quantitative impact on biodiversity, water and air quality could not be addressed in this study. However, they are likely to be positive but small in magnitude. Some of these issues are discussed in the report of Task 1 Part 2.

Specifically this task evaluated the effect of the scenario simulating a 5% increase in the baseline in grassland in the year 2020 with respect to the baseline (TSCAL) on other environmental parameter. We assess in particular (a) the effect on the gross nitrogen balance (N-surplus according to the land nitrogen budget); (b) the effect on CH₄ emissions from enteric fermentation and total methane (CH₄) emissions from rice cultivation, enteric fermentation and manure management; (c) the effect on nitrous oxide (N₂O) emissions from agricultural soils and manure management; (d) the effect on ammonia (NH₃) emissions; and (e) carbon sequestration.

At EU27 level, emissions of methane and nitrous oxide increase slightly by 0.3% and 0.14%, respectively. This is mainly relates to changing animal numbers, generating higher manure N, which is partly compensated by lower applications of mineral fertiliser at an overall slight increase of total UAA.

The increase of grassland naturally leads to an increase of carbon sequestration according to the data and methodology used in CAPRI. This increase corresponds to a decrease of opportunity emissions of CO₂ related to carbon sequestration of 3.16%. This difference might be interpreted as 'real' increase in carbon sequestration, as the reference situation is irrelevant. Comparison with a calculation on the basis of the results of the Century model (see Task 4) with an average carbon sequestration rate of 3.1 t CO₂ ha⁻¹ yr⁻¹ applied to the increased area of permanent grassland (2.7 Mha) in the CAPRI regions sums up to a total of 8.5 Mt CO₂ yr⁻¹. However, also total UAA increases in the CAPRESE scenario with respect to the baseline and the previous use of this land (0.7 Mha) is unknown. We therefore calculate a lower range on the basis of the Century data of 6.4 Mt CO₂ yr⁻¹. These slightly higher estimates reflect the fact that even though continuing for a long time, carbon sequestration rates will decrease with time so rates are likely to be higher during the first decade.

The resulting effect on total CO₂ emissions of 5 Mt CO₂eq yr⁻¹ corresponding to a decrease by ca. 1% or 1.5% if compared with CH₄ and N₂O emissions only. Additional carbon sequestration calculated with the Century model would save about 1.9% - 2.5% of the sum of CH₄ and N₂O emissions in the baseline.

However, the increase in grassland area triggers also a change in net trade with increasing imports, by almost 7%. Even though this effect has not been analysed in detail in the current report, a rough estimate can be done on the basis of LCA factors which suggest that the additional import of about 1.3 Mt of cereals would lead to a 'leakage' of emissions in the order of magnitude of 0.9 Mt CO₂eq yr⁻¹, partly compensated (-0.35 Mt CO₂eq yr⁻¹) by reduced import of soy cakes (ca. 280 kt) that are associated with higher CO₂eq emissions per units .

Again, grassland area satisfies multiple ecosystem services that go beyond emissions of reactive nitrogen and greenhouse gases. These effects (which as well have not been addressed in this report) are likely to be small but positive. The overall assessment requires a careful balancing of these different impacts.

6. Task 6: Delineation of policy options and monitoring tools

On the basis of the findings presented in Tasks 1-5, this task presented policy options that are appropriate in order to promote the introduction of the mitigation measures in the agricultural systems (e.g. incentive payments, legal obligations, voluntary certification, market based instruments, etc.) and the broader environmental context (soil protection). Policy options have been linked to existing policy tools such as cross-compliance, rural development measures and related legislation.

Soil Thematic Strategy or measures foreseen in the potential “greening” of the CAP.

Unlike the control of cropping practices, the evaluation of the state and trends of SOC stocks is complex and needs to be carried out over long time periods to show viable trends. The work package will review potential methodologies and procedures for the monitoring of changes in SOC stocks at farm and regional level. Specifically, the work package will assess whether the information needed to monitor the implementation and effects of the mitigation measures at farm level is readily available. These requirements will be analysed in relation to the policy framework under which mitigation measures will be supported (e.g. CAP, market approaches).

The definition of the policy options shall take into account the induced costs born by the farmer. Options for financial support in order to implement such measures should be given. It should also develop recommendations on how mitigation measures can be enhanced through appropriate policies at national level.

The study shall evaluate the costs of the possible implementation of the policies. An assessment shall be carried out to investigate if linking carbon farming to carbon market (including non-CO2 emissions) would be feasible and cost-efficient.

The monitoring and controlling system to be proposed should be linked to instruments already developed in the CAP IACS (Integrated Administration and Control System) such as the methodologies for control of payments and the LPIS (Land Parcel Identification System).

In conclusion, the CAPRESE project will build on the work done in related projects such as AFO-CC (Policy scenarios and future GHG emissions from agriculture and forestry), LULUCF MRV (Enhancing monitoring, reporting and verification of GHG from land use, land use change and forestry in the EU) , PICCMAT (Policy Incentives for Climate Change Mitigation Agricultural Techniques) and SOILSERVICE (Conflicting demands of land use, soil biodiversity and the sustainable delivery of ecosystem goods and services in Europe).

Given the relatively short timescale of the project, a key aspect of this work package will be the identification of key follow-up targets that would require more, in-depth analysis or additional resources (e.g. new physical or financial models).

Specifically, this task presented:

- Guidelines for policy development on potential mitigation options for soil carbon levels
- Draft guidelines for protocols/methodologies for quantifying soil carbon stocks and for improved monitoring of changes

- Conclusions regarding the impact on production for selected mitigation measures
- Recommendations on monitoring and controlling systems
- Financial implications of potential mitigation options and links to possible funding instruments
- Recommendations in light of rural development strategies
- Implications from LULUCF strategies

7. Description and access to the modelling platforms

7.1 CENTURY

CENTURY is a process-based model designed to simulate C, Nitrogen (N), Phosphorous (P) and Sulphur (S) dynamics in natural or cultivated systems, using a monthly time step. The soil organic matter sub-model includes two fresh residue pools (litter) and three SOC pools. Litter is subdivided in two pools (metabolic and structural) and SOC into three pools (active, slow, and passive). The metabolic litter pool represents easily decomposable constituents of plant residues, while the structural litter pool is composed of more recalcitrant, lignocellulose plant materials. The three SOC pools represent a gradient in decomposability. Active SOC is microbial biomass and associated metabolites having a rapid turnover (months to years), slow SOC has intermediate stability and turnover times (decades), and passive SOC represents the highly processed and stabilized products with longer turnover times (centuries). The decomposition of both plant residues and SOC are assumed to be microbially mediated with an associated loss of CO₂ (as a result of microbial respiration), which is influenced by soil texture. Decomposition products flow into a surface microbe pool or one of three SOC pools. The potential decomposition rate is reduced by multiplicative functions of soil moisture and soil temperature and may be increased as an effect of cultivation. The model is also able to simulate the water balance, using a weekly time step, and a suite of simple plant growth models are included to simulate C, N, P and S dynamics of crops, grasses and trees. Plant growth and net primary production is simulated according to the genetic potential of the plant, temperature, and availability of moisture and nutrients. The plant growth model determines the type and timing of the net primary production that is allocated to the different SOC pools.

CENTURY was selected as the most suitable model for a pan-European SOC assessment since: 1) crop growth routines are integrated for both herbaceous and trees crops (e.g. orchard, vineyard, etc.), including the possibility to simulate mixed systems; 2) the model has been tested successfully in several European countries (Lugato et al., 2006, 2007; Álvaro-Fuentes et al., 2012a); 3) the effect of the main management practices in the agricultural fields are simulated (tillage, grazing, irrigation, fertilisation etc.); 4) the monthly time step reduces the computational time when dealing with a large number of combinations.

For this study, the model was run with the coupled C-N sub-models.

Additional simulations are available on request.

Future development

The modelling approach for estimating SOC stock under current management and future mitigation options is undoubtedly one of the most cost-effective techniques. Although the limited amount of time to develop the platform of simulation, the results are very promising in term of model accuracy and flexibility in assessing different agricultural mitigation managements.

Moreover there are still large margins of improvement related to:

1. Model accuracy: the model has been validated with the large LUCAS dataset and regional/national SOC estimation from EIONET, but several national, sub-national and field data (soil, biomass, fluxes etc.) exist to further improve its accuracy.
2. Model run-time process: while scenarios can be easily created, the simulations can last even a week depending of the number of combinations involved. A parallel computation with computer clusters, likely reducing the run-time process of order of magnitudes, is possible but it would require some investment to convert the system towards this configuration.
3. Model usability: due to the scripting and absence of a GUI, the platform can be run only by the developer. In order to make the results available for a broad community (policymakers, scientists, farmers etc.) a web-gis user friendly interface may be developed to easily access to model outputs. Moreover, there is the potential to run the model on line with local data directly implemented by the user (eg. farmer for instance), as done in the COMET farm system (<http://cometfarm.nrel.colostate.edu/>) enabling a farm level carbon and greenhouse gas accounting system.

7.2 Description of CAPRI (including Farm-Type) model

The CAPRI modelling system is a comparative-static partial equilibrium model, which iteratively links a supply module, focusing on the EU, Norway, Turkey and Western Balkans, with a global multi-commodity market module. The global trade model covers 77 countries (or country aggregates) in 40 trade blocks. It consists of specific data bases, a methodology, its software implementation and the researchers involved in their development, maintenance and applications. The supply model consists of 224 administrative regions (NUTS2).

Each administrative region is represented by a non-linear programming model. Each model optimises aggregated farm income under restrictions relating to land balances, including a land supply curve (see below for details), nutrient balances and nutrient requirements of animals and if applicable, to quotas and to set-aside obligations. Decision variables are crop acreages and total land use, herd sizes, fertiliser application rates and the feed mix. Premiums paid under the CAP are captured in detail. The allocation response rests largely on non-linear objective function terms, which are either econometrically estimated or derived from exogenously given supply elasticities.

The supply models are a compromise between a pure LP approach and the fully econometrically estimated one. The compromise is achieved by combining a Leontief technology for variable costs covering a low and high yield variant for the different production activities with a partially econometrically estimated non-linear cost function based on the Positive Mathematical Programming (PMP) approach. The non-linear cost function captures the effects of labour and capital on farmers decisions. Its advantage is that it allows perfect calibration of the supply models and a smooth simulation response to policy changes

Specific modules ensure that the data used in CAPRI are mutually compatible and complete in time and space. They cover about 50 agricultural primary and processed products for the EU, from regional level to global scale including input and output coefficients. Prices are

endogenously determined by the market module in an iterative process solved between the supply and market modules until convergence is reached. The Armington approach assuming that the products are differentiated by origin, allows the simulation that the products are differentiated by origin, allows the simulation of bilateral trade flows and of related bilateral and multilateral trade instruments, including tariff-rate quotas. The CAPRI modelling system allows for the economic and environmental analysis of different policy scenarios regarding the reform of the Common Agricultural Policy and its successive reforms. It is able to perform a regional level analysis of specific Common Market Organisations (e.g. sugar, dairies), trade of agricultural goods with the rest of the world (e.g. WTO proposals) and different subsidy schemes in Europe (e.g. partial decoupling of agricultural subsidies). The model was initiated in 1999 and is currently considered a key model for the European Commission reporting on agricultural and agri-environmental policies at the regional dimension. It has been continuously used by DG-AGRI, DG-ENV and the JRC (IPTS and IES) during the last 5 years.

The CAPRI Farm Type (CAPRI-FT) is a component of CAPRI modelling system. The CAPRI-FT mainly aims to capture heterogeneity in farming practises and farm types within a region, in order to reduce aggregation bias in response of the agricultural sector to policy and market signals, with a specific focus on farm management, farm income and environmental impacts. The CAPRI-FT is built from the FADN and the Farm Structure Survey (FSS) data. The CAPRI-FT consists of independent non-linear programming models for each farm type aggregated over all activities belonging to a given farm type and a specific NUTS2 region. The farm models, similar to the regional ones, capture the premiums paid under the CAP in high detail; include NPK balances and a module with feeding activities covering nutrient requirements of animals. Besides the feed constraint, other model constraints relate to arable land and grassland. Grass, silage and manure are assumed to be non-tradable and receive internal prices based on their substitution value and opportunity costs. The farm groups are characterized along two dimensions (Table 1): (i) by production specialization and (ii) the economic size class of farm represented in terms of European size units (ESU). We consider 13 production specializations and 3 farm sizes. In total, this leads to 39 farm types. In order to set the number of farm types per NUTS2, a selection routine has been implemented in which it is maximized at EU-27 level the represented Utilised Agricultural Area (UAA)+Livestock Units (LU) of all the selected farm types, constraint to a maximum number of farm types at EU-27 level. The maximum number of FT selected has been set to 2224 (and 225 residuals).

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