EIP-AGRI Focus Group
Moving from source to sink in arable farming

STARTING PAPER

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Introduction

Agriculture is highly exposed to climate change, as farming activities directly depend on climatic conditions. Not only should it produce food and feed without having net losses of carbon, but also to produce raw material for a future biomass based economy. Agricultural practices might also contribute to generate emissions when soils are intensively managed and their capacity to store carbon is decreased. At the same time, agriculture can significantly contribute to climate change mitigation by reducing greenhouse gas emissions and by storing carbon in plants and soils. Globally, soil contains about three times as much carbon as plants and twice as much as the atmosphere. There is a large potential for storing carbon in agricultural soils and thus for mitigating climate change (Lal *et al.*, 2011). According to estimates from the United Nations Framework Convention on Climate Change (UNFCCC), an increase in carbon storage of 0.4 per mille would be enough to counteract a large part of today's greenhouse gas emissions to the atmosphere (UNFCCC, 2016).

Arable soils are on global level low in organic matter content, and this provides a great opportunity to increase carbon storage (Lal *et al.*, 2011). Across Europe the situation is similar and many soils are depleted in soil carbon, which can be identified from monitoring activities by the European Commission (Panagos P, 2013) where 50% of arable EU soils are regarded as low in soil carbon and more than 10 M ha subject to erosion (Hammel, 2013), Fig 1.

The capacity of soils to store carbon depends on a wide range of soil factors that can be improved by appropriate management techniques. There is great scope for getting interest and actions from farmers when it is possible to show positive co-benefits or so called ecosystem services of their management on e.g. promoting soil carbon sequestration in connection with higher yields, improved soil structure, less fertiliser use given by retention of nutrients, reductions in soil bulk density, improved water holding capacity and higher biological activity but not the least resulting in long-term higher profits (Barrios, 2007; Bolinder *et al.*, 2010).

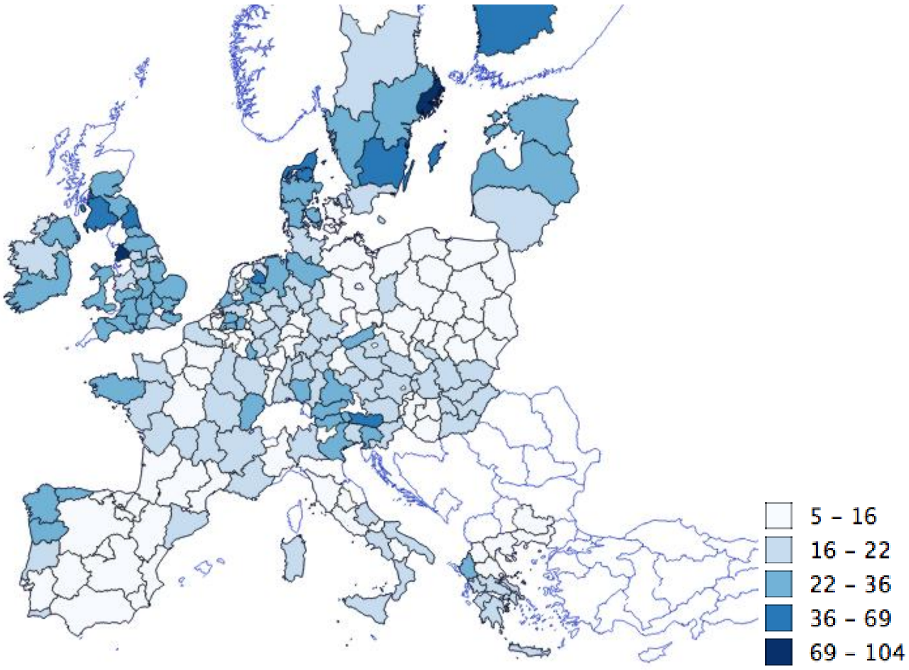

Fig 1. Soil organic carbon (g/kg) 2009 in arable land from the LUCAS soil inventory, aggregated on NUTS2 level (Eurostat)

The focus groups will address the question:

Which cost-effective farm management practices and tools could foster and ensure long-lasting carbon storage in arable farming, contributing to climate change mitigation?

The specific objectives of the focus groups are:

- **Take stock of the current practices and tools** which could foster long-lasting carbon storage in soils and improve soil quality in the different geographical and climatic conditions of the EU. **Identify challenges and opportunities.**
- **Collect good practices and success stories** from different European areas, especially focusing on farmers' and advisers' experiences.
- **Compare different management practices** taking into account the feasibility and cost-effectiveness at farm level.
- **Identify success factors** (such as knowledge requirements, partnerships) **and technical/economic/social barriers, or fail factors**, concerning the adoption of practices fostering carbon storage in arable farming.
- **Discuss how these practices may be transferred to other conditions** (location, type of production).

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- **Suggest innovative solutions and provide ideas** for EIP-AGRI Operational Groups and other innovative projects.
- **Take stock of the state of play of research. Identify needs from practice and possible gaps in knowledge** concerning carbon storage capacity in arable farming that may be solved by further research.

The purpose of the starting document is to:

- Establish a common understanding about the purpose of the Focus Group;
- Provide the background on arable farming and soil carbon sequestration
- Provide an overview of current and potential practices in order to promote and implement management of soil carbon sequestration.
- Provide examples of gaps in knowledge and research, for further discussion.
- Identify key questions for discussion at the first Focus Group meeting.
- Summarise answers to the questions asked in the preparatory questioner to the focus group members

What challenges and opportunities can be identified when promoting soil carbon sequestration at arable farming?

To change agricultural management in order to increase soil carbon sequestration there have been multiple ways of informing on best management practices, and development of a number of different tools from e.g. scientific evidence, policy or from farmers' advisors. With the long experience of long-term agricultural experiments there is a large evidence base that can be used to make general predictions soil carbon sequestration and agricultural management (Haddaway *et al.*, 2015). A range of management activities have been tested and there is ample evidence on effects of management to be synthesized which can provide best practices for farmers of different regions.

Challenges

Arable soils are currently loosing soil carbon of around 0.2 to 1% if their soil carbon annually (Morari *et al.*, 2006; Riley and Bakkegard, 2006; Senthilkumar *et al.*, 2009). The rate of soil carbon change is often determined across regions by combining a number of management practices and differences in soil types and measured at a few points in time (Meersmans *et al.*, 2011). In long-term agricultural experiments, it is evident to several management practices actually loose soil carbon when SOC stocks are recorded over many years, thus allowing rates of change due to management practices to be estimated (Brady *et al.*, 2015). It has been highlighted that even though single management practices can be shown to promote soil carbon there may still be a general overall negative rate of change of soil carbon (Sanderman and Baldock, 2010) as shown in a conceptual graphs from experiments in Australia where management depleted stocks of SOC (Fig 2).

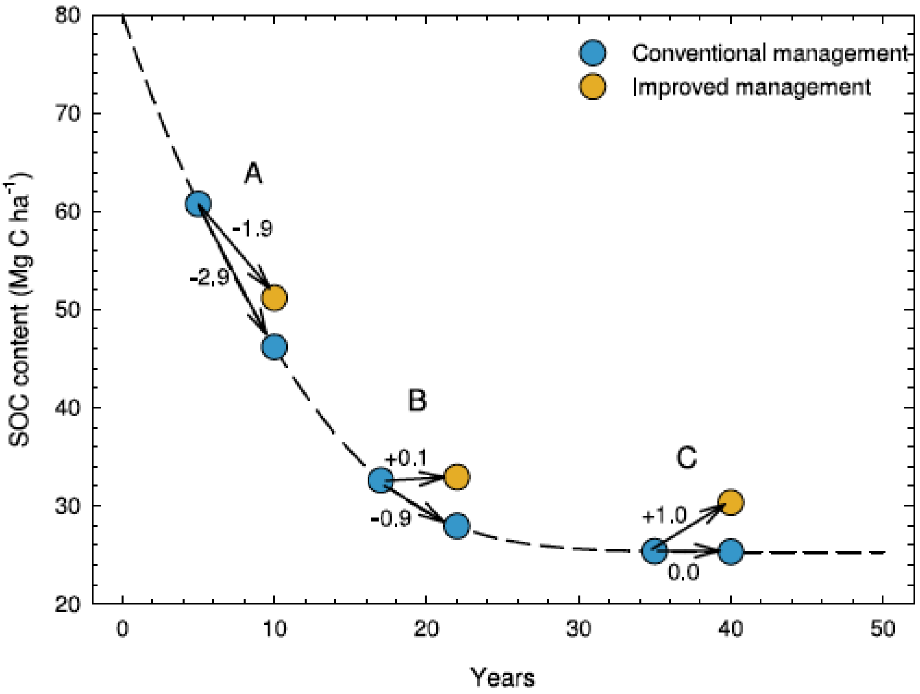

Fig 2 A conceptual graph of soil carbon decline and the end points of agricultural experiment. (Sanderman and Baldock, 2010)

In order to change this process there are also a number of challenges that may trade off positive impact from management, that are listed below:

- Keeping the production levels in arable farming while promoting SOC levels. IS this always a win-win relationship or are there negative trade-offs?
- Food safety and impact of the re-use of organic resources, as sewage, farm yard manure or compost.
- Spatial allocation among regions having life stock and arable farming, makes the use of manure costly to use in arable farming.

- Future land use predictions as for conservation of biodiversity or production of biomass and offsetting arable production, will this influence the management to promote soil carbon?

Opportunities of increasing C sequestration in agricultural soils

There are multiple co-benefits from increasing soil carbon among other soil ecosystem services –for the farmer, as well as society. This can certainly act as drivers for implementation, as it may reduce loss of biodiversity, a higher water retention and retention of nutrients in the soil. Introduction of new policies into the EU regions, as not only to provide food and feed but also to produce biomass for a coming market to fulfil policy like the Bioeconomy strategy[1]. A demand for biomass for energy and industry increase the request for feedstocks that could be integrated into the arable farming and be beneficial mitigate climate change and also store more soil carbon as in the case of Miscanthus grasses (see table 1).

There are also a number of initiatives starting to depict the values of soil carbon to farmers and society that may help to cover transaction costs of promoting soil carbon. A number of initiatives to increase the knowledge of soil carbon benefits and soil carbon monitoring have been taken, such as:

- Technological innovations; as SOC monitoring (manual or spectral analyses) across all member states as the LUCAS soil database (Panagos P, 2013).
- Development of precision farming with sensors for soil carbon when allocating fertilisers or organic amendments.
- Communication on benefits of soil carbon and agriculture both to farmers and society[2] .
- Farmer organisations, NGO's FAO, global soil assessment framework IPCC, that will promote the values of soil carbon to a wider audience

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[1] http://ec.europa.eu/research/bioeconomy/index.cfm?pg=policy&lib=strategy

[2] https://www.nature.com/news/agriculture-engage-farmers-in-research-1.15108

What are the evidences for best practices of C-sequestration in arable farming?

Among the evidence of how soil carbon can be influenced in farming generally the factors tillage, organic or crop residue amendments, fertiliser types and rates, and crop rotation schemes are addressed and there is a large scientific evidence base present in the topic. In order to synthesise knowledge a number of different reviews and initiatives have been taken, as a systematic map of scientific evidence (Haddaway *et al.*, 2015) and EMAS[3] best practice protocol outlining some of most best practices and locally a number of best practices documents like e.g. the Welsh good agricultural practice code Environmental Evidence (WAG, 2010).

Can management practices as tillage, amendments, crop rotation, and fertilisation promote soil organic carbon?

Tillage has been discussed as one of the major management practice that may influence carbon sequestration and has been related to loss of C due to ploughing (Reicosky, 2003). Recently there has been an adoption of reduced tillage practices that aim at increasing soil carbon concentration especially in the topsoil, as eg conservation tillage, that also reduce the use of fuel during tillage (Holland, 2004). In a recent systematic review with a meta analyses of published data of around 300 studies on tillage effect on soil organic carbon, reduced and no tillage practices can sequester more carbon than conventional tillage in the soil upper layers, see Fig 3.

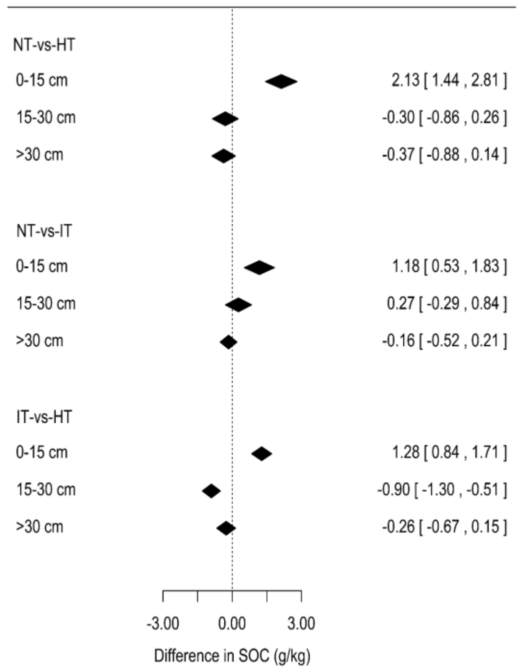

Fig 3 Meta analyses of global data on soil tillage and SOC g/kg NT- no tillage, IT. Intermediate tillage, HT Intensive or conventional tillage. (Haddaway *et al.*, 2017)

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http://ec.europa.eu/environment/emas/emas_publications/sectoral_reference_documents_en.htm

There has also been discussion on whether the reduced tillage practice may cause other types of negative impact such as a higher pesticide use, lower yields or higher N_2O emissions (Basche *et al.*, 2014; Pittelkow *et al.*, 2015)

In EU the use of reduced tillage varies between the countries and in an inventory from 2010 data is present on NUTS2 level for the EU member states on how common the practices were. In fig 4 and maps in Appendix A1 and A2 we can see that some countries have much more intensive tillage than others as in the eastern regions. Other sources reports higher levels of reduced tillage and as high as 40-60 % of farmers in the UK and Sweden (Hedlund and SoilService, 2012; Knight *et al.*, 2012).

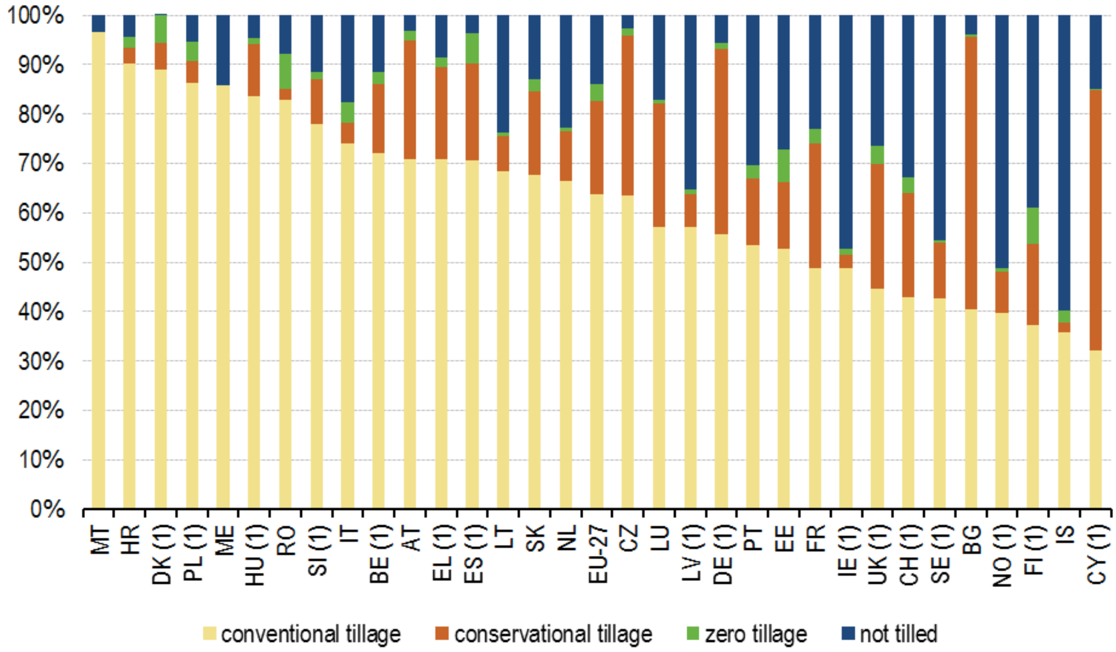

Fig 4 Tillage practices in EU member states 2010, (Eurostat)

Cover crops, winter crops and perennial crops

The soil carbon levels in soils are an outcome of the carbon converted into plant biomass as well as soil organisms and with losses through decomposition processes. Not only the above ground plant parts are responsible for the sequestration but also root-derived carbon is highly important to soil carbon (Rasse *et al.*, 2005; Menichetti *et al.*, 2015) Thus, perennial crops and inter-crops or cover-crops are shown to promote soil carbon more than annual crops since they allocate a larger portion of C into roots and root exudates (Ladygina and Hedlund, 2010). Crop rotations with perennial grass leys can thus promote the soil carbon through the grass roots (Kätterer *et al.*, 2011). Though field experiments on cover crops or intercropping are more recent and have not produced so much evidence yet which provide longer time series of data.

Amendments and crop residues

Practices concerning amendments can be either to retain the crop residues and to incorporate these into the soil or organic material, or to use organic material that is not produced on the field but could be recycled material from household compost or sewage sludge. Long term effects on soil carbon from crop residues is highly variable and has often shown non-significant effects (Powlson *et al.*, 2011; Liu *et al.*, 2014; Poeplau *et al.*, 2015). In a long-term experiment in Denmark, long term application of straw only showed a positive increase of soil carbon when 12 tons/ha of barley straw was added to the soils, which corresponded to twice the amount of what the field produced, see Tab 1. Amendments of organic residues as sewage sludge has in experiment doubled the soil carbon in 20 years experiment in Sweden (Bolinder *et al.*, 2010) though other environmental effects such as concerns of residues of pharmaceuticals and heavy metals have influenced the use and regulations of sewage in Europe.

Applications of organic manure are generally regarded as positive for soil carbon (see tab 1) but when given in very high amounts the leakage of nutrients may cause problems as eutrofication of surface waters. Fertilisation also be inorganic fertilisers increase the roots and plant biomass thus also putting more carbon in the soil and reducing the losses of carbon, but still not stopping the negative losses (Brady *et al.*, 2015). Across the member states the application to cover the soil surface varies greatly between the member states and winter wheat is the dominating crop but often there is no coverage during the non-cropping season, see fig 5, and maps in the Appendix (Figs A2 to A6). The applications of cover or intermediate crops on nonwinter wheat fields are also variable among countries and the reason behind the variation could achieve more attention.

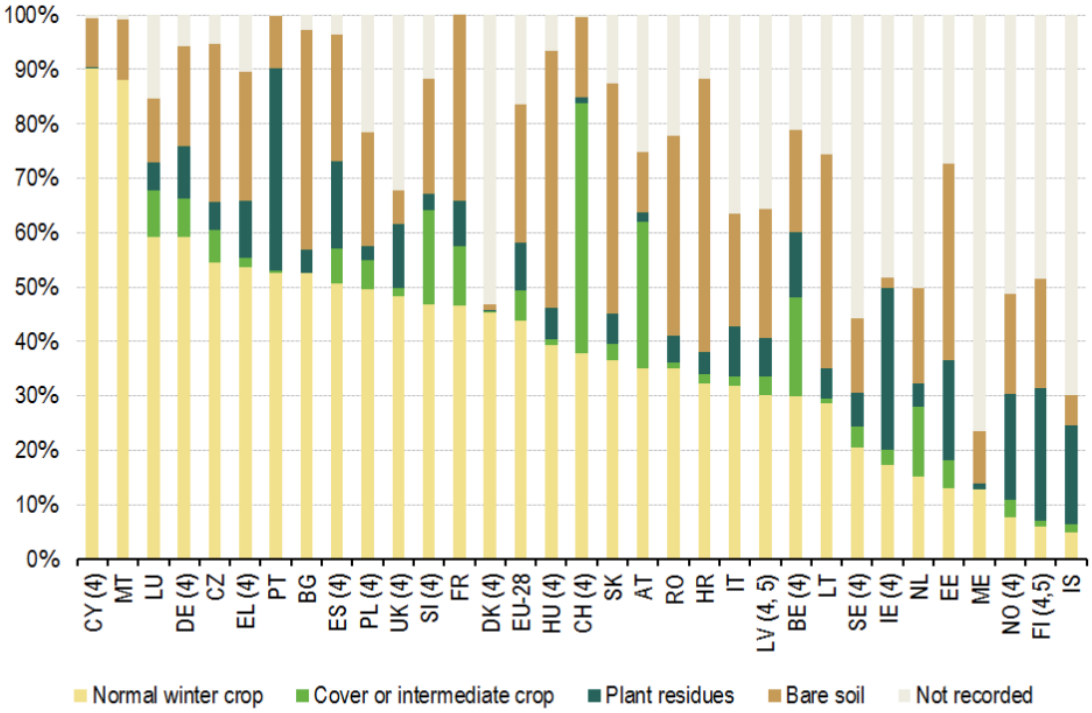

Fig 5 Soil cover practices in EU member states 2010, (Eurostat)

Crop rotations

Crop rotations are among farmers an important tool to both reduce diseases and weeds but also to promote soil carbon. Perennial grass leys can provide soil carbon through the grass roots and the through the promotion of the soil organisms that are boosted by this (Kätterer *et al.*, 2011; Tsiafouli *et al.*, 2015). Though there is a lack of scientific synthesis of the area although multiple studies are present in the scientific literature (Haddaway *et al.*, 2015). Studies of crop rotations are often confounded with other practices as fertilisers, tillage and difficult to evaluate, but there is a good range of evidence that could be used for evaluation (Haddaway *et al.*, 2015).

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How are long- and short-term aspects influencing implementation and C sequestration?

Sequestration of soil carbon is a long-term process as there is a time lag from the production of organic material from a plant until it is transformed through biomass of organisms and then further decay in the soil food web, and the soil organic material that is stored in soils is generally what is not anymore possible to decompose. Data from long term experiments show that it takes at least 10 years to detect an effect of a changed management on the soil organic carbon levels (Brady *et al.*, 2015). Decisions on practices may however be more short term depending on prices of crops and incentives for promoting soil carbon. There are a number of tools available (see below) to show case the effects on soil carbon development with different types of management and the resulting economy for farmers and generally they predict that a long term investment will pay off in the future (Hedlund and SoilService, 2012).

When summarising the rates of change of soil carbon in arable production, see table 1, an increase rate of 0.1 % of a soil that already has a concentration of 1.5% means an annual increase of around 0.15 % in one year, so the built up of soil carbon takes a long time.

Table 1 Examples of soil carbon decline and increase rates from long term experiments.

Management Practise	**Rate of C change per**	**Site/CountryReferences**
Long term experiments	*Decline (relative to C*	
Inorganic fertilizers	-0.2%	Rothamsted UK (Johnston *et al.*, 2009)
Farm yard manure (5 ton/ha/yr)	-0.2%	Scania SE (Brady *et al.*, 2015)
Straw returned (4 ton/ha/yr)	-0.5%	Scania SE (Brady *et al.*, 2015)
Inorganic fertilizers	-3.0%	Padova Italy (Morari *et al.*, 2006)
Inorganic fertilizers)	-0.3%	Michigan US (Senthilkumar *et al.*, 2009)
Regional farming practices		
Conventional farming/ Crop rotation	-0.2%	Flanders BE (Meersmans *et al.*, 2011)
Conventional farming/ Crop rotation	-1.0%	Norway (Riley and Bakkegard, 2006)
No-till/ Maize production	-1.5%	South Dakota US, (Clay *et al.*, 2012)
	Increase	
Cover crops	0.1%	Ultuna SE (Kätterer *et al.*, 2011)
Straw addition (12 ton/ha/yr)	0.3%	Askov DK (Brady *et al.*, 2015)
Farm yard manure (35 ton/ha/yr)	0.4%	Rothamsted UK, (Johnston *et al.*, 2009)
Sewage sludge (2 ton C/ha/yr)	1.0%	Ultuna SE,(Bolinder *et al.*, 2010)
Miscanthus grass (bioenergy crop)	2.0%	Illinois US (Davis *et al.*, 2012)

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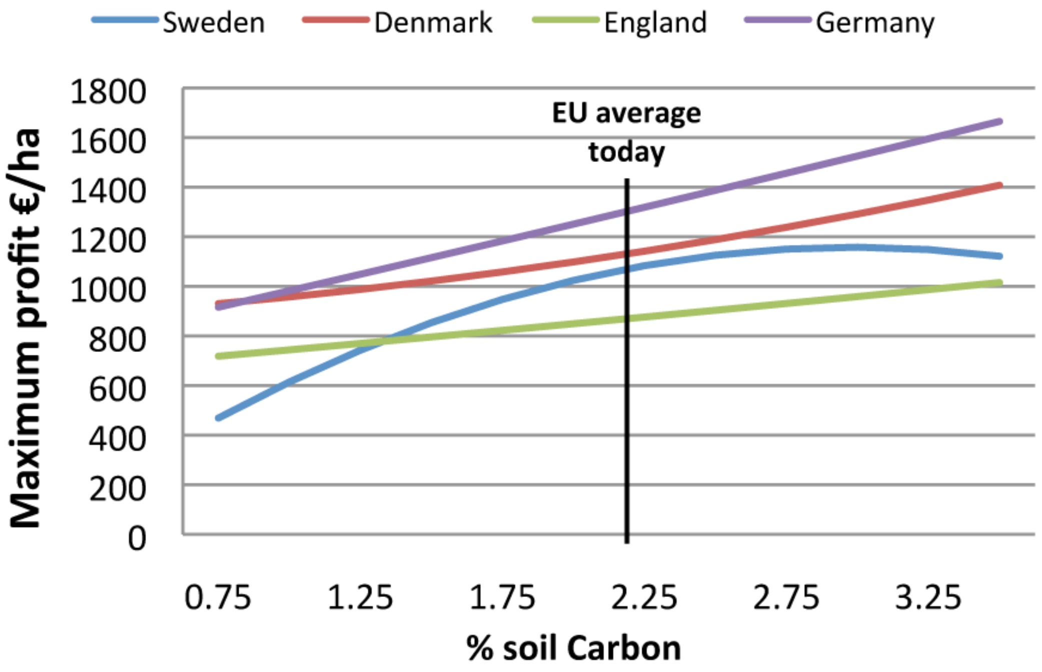
How can values of soil carbon be used as drivers of implementation?

Values of soil carbon sequestration in arable land are important for estimates of the cost efficiency of the practices that can determine the values of the soil fertility or the soil natural capital which can give future profits for the farmer. The soil carbon can also help to reduce fluctuations dependent on too little or too much water and will serve as an insurance for more stable yields (Cong *et al.*, 2014). From a societal view the value of carbon sequestration in soils can be valued as a common good in order to mitigate climate change and be given values such as global carbon credits.

The value of soil carbon can be viewed as an input to the production and form a part of the basis for production, thus its value is the contribution to a higher yield and to the farmers economy. The information on the value of carbon to business models is important in order to show the long-term effect on profits. From agricultural experiments in 4 European countries changes in soil carbon was related to farmers profits, by a EU research project see fig (**http://www.biology.lu.se/research/research-groups/soil-ecology/research-projects/soilservice**).

Fig 6 Relations between changes in soil carbon and farmers profits across Europe, based on long term experiments and reported by the SOILSERVICE project (Hedlund and SoilService, 2012).



Research: recent knowledge and knowledge gaps

There is a huge bulk of knowledge on soil carbon and arable farming but this still lacks systematic synthesis in order to statistically evaluate different management methods and how they influence soil carbon sequestration (Haddaway *et al.*, 2015). The estimates of costs and values of benefits of management is also in need of more synthesis and development of valuation models, as this will greatly improve the possibilities to implementation.

The scientific evidence is often published in scientific journals and datasets from long-term experiments are not accessed easily for users outside the scientific community, but several initiatives have been taken to promote open access databases like in the German Bonares project (**https://www.bonares.de/)**. Monitoring data is often open access but with few points and in time, as the recent soil database from the LUCAS inventory (ref).

Examples of knowledge gaps for inspiration in the group:

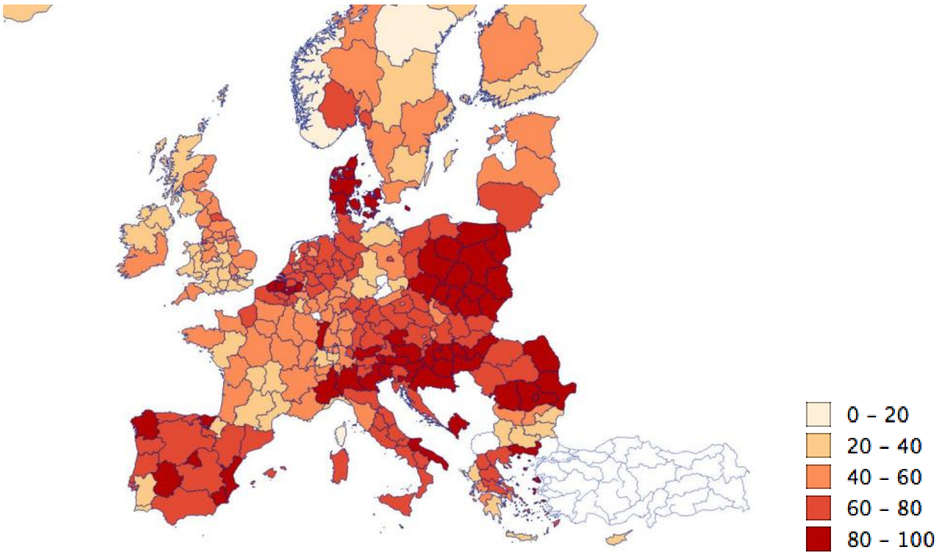
- Mapping the C-sequestration potential of arable land, and regional aspects on factors influencing soil carbon sequestration
- Synthesising knowledge on Soil C and management on global level
- Bridging research knowledge to farmers and policy; here a number of tools have been developed as:
    - UK farm tool: **http://www.farmcarbontoolkit.org.uk/**
    - C-tool Taghizadeh-Toosi et al 2014,
    - Smartsoil:**http://gefionau.dk/projectnet/smartsoildst/Pages/MainLearningModule.aspx?Language=en-GB**
    - C-bank: **http://c-bank.lu.se/**
- Open access data bases of scientific knowledge
- Open access data from long term experiments
- Knowledge and awareness of incentives, strategies and policies influencing Soil C sequestration (regional, national and EU)

Appendix

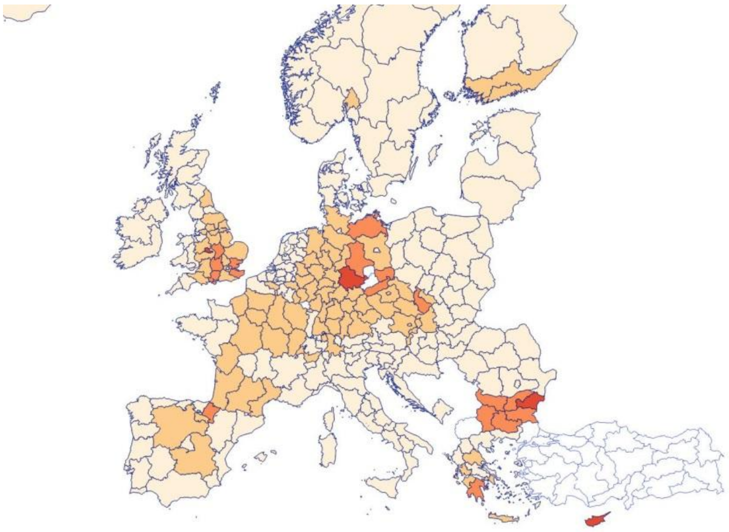
Figur A1

Tillage practices per area arable land (%) of on NUTS 2 level at 2010, Eurostat xxx database.

a) Intensive tillage (%)



b) Reduced tillage (%)



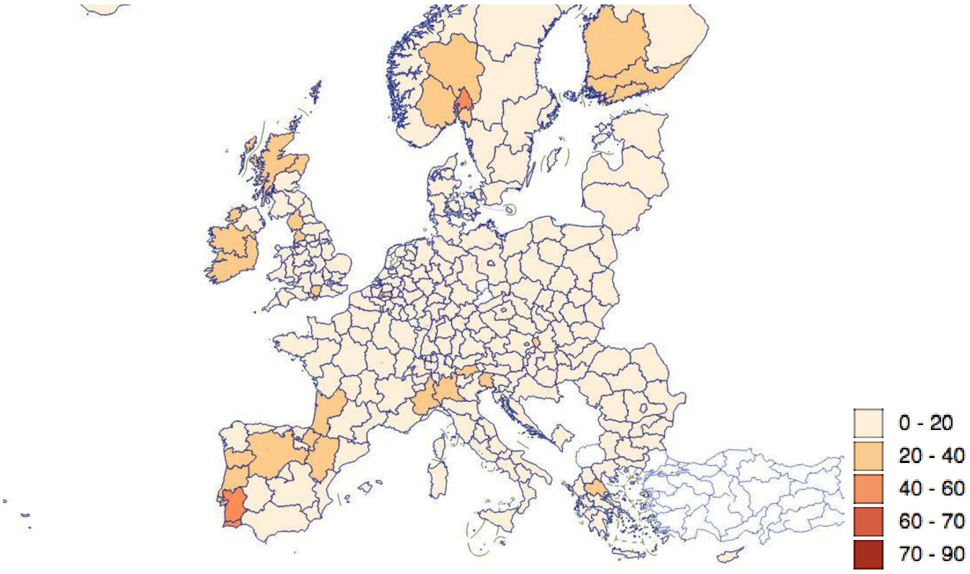


Fig A2 Harvest residue application on arable farms in 2010, Indicates the percent of area that has the application. (Eurostat)

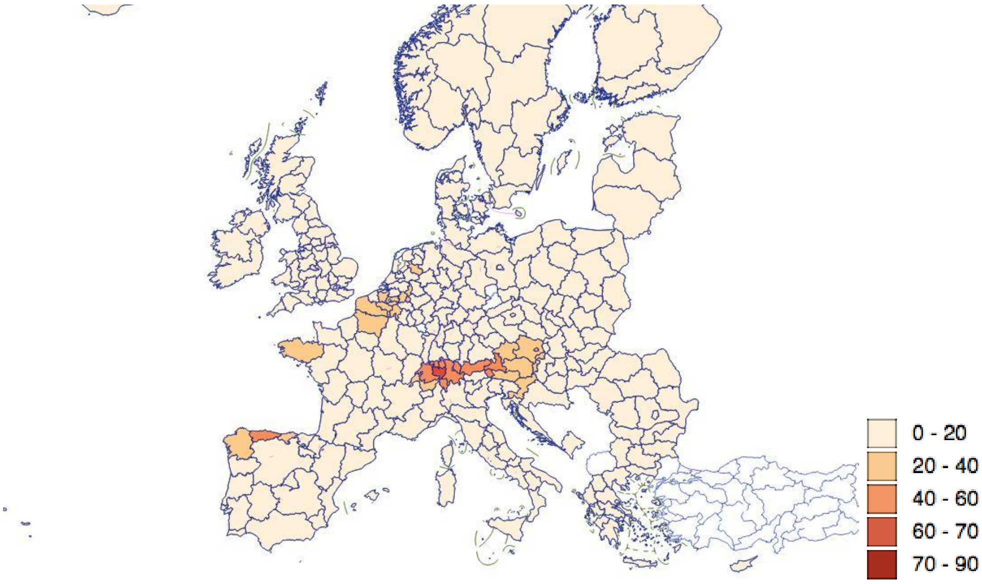


Fig A3 Cover crop application on arable farms in 2010, Indicates the percent of area that has the application. (Eurostat)

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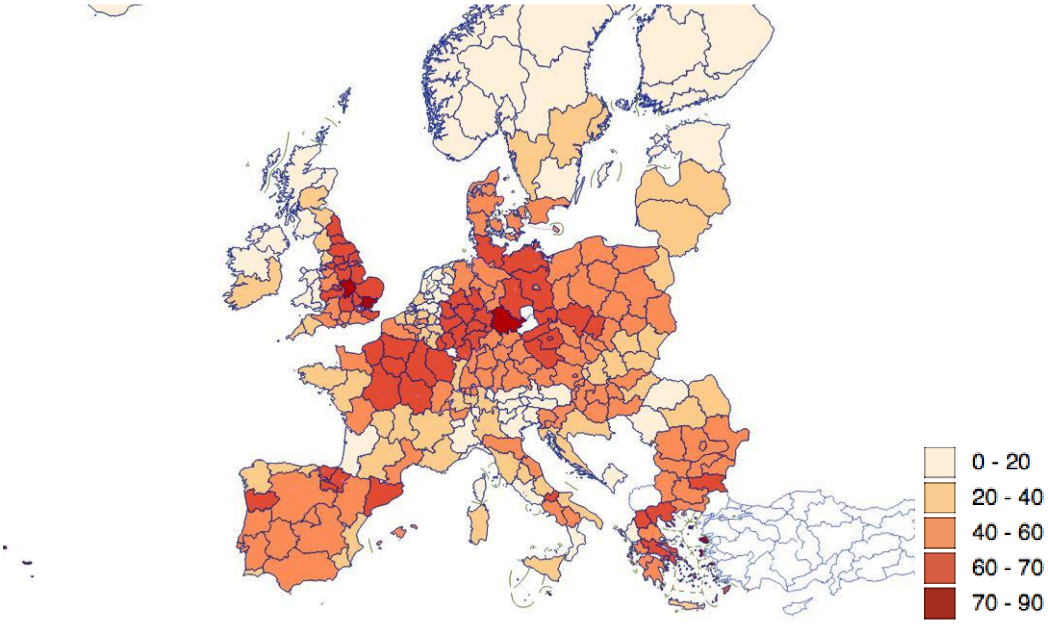

Fig A4 Winter wheat cover 2010 (Eurostat)

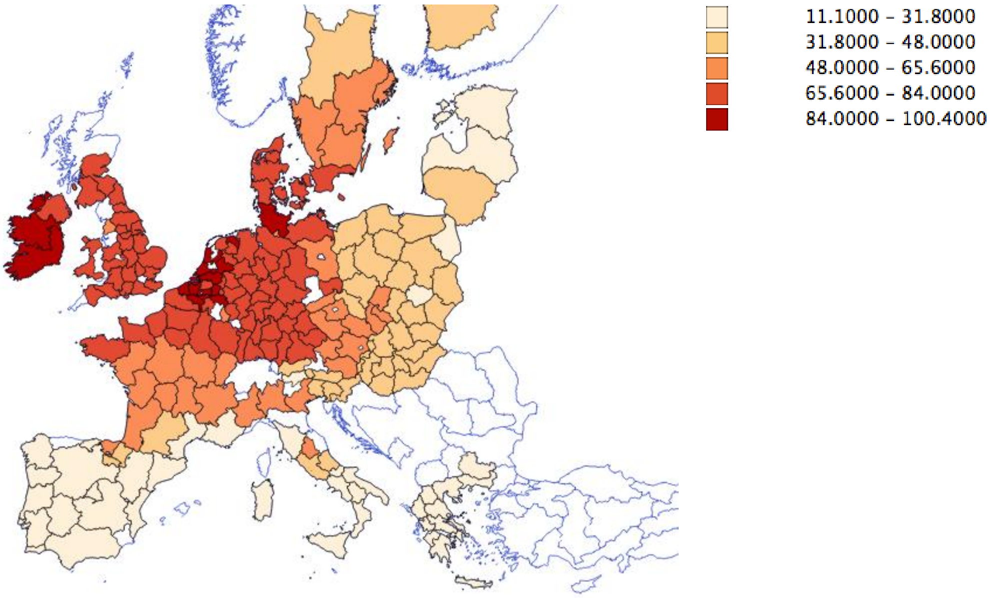

Fig A5 Winter wheat yield 2009 (Eurostat)

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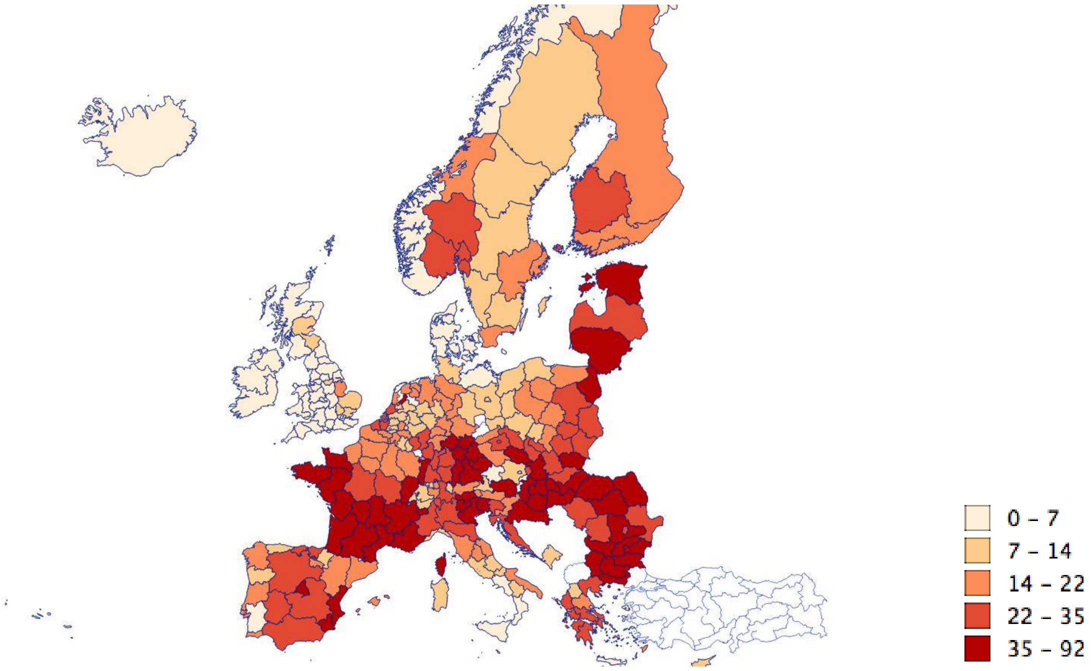
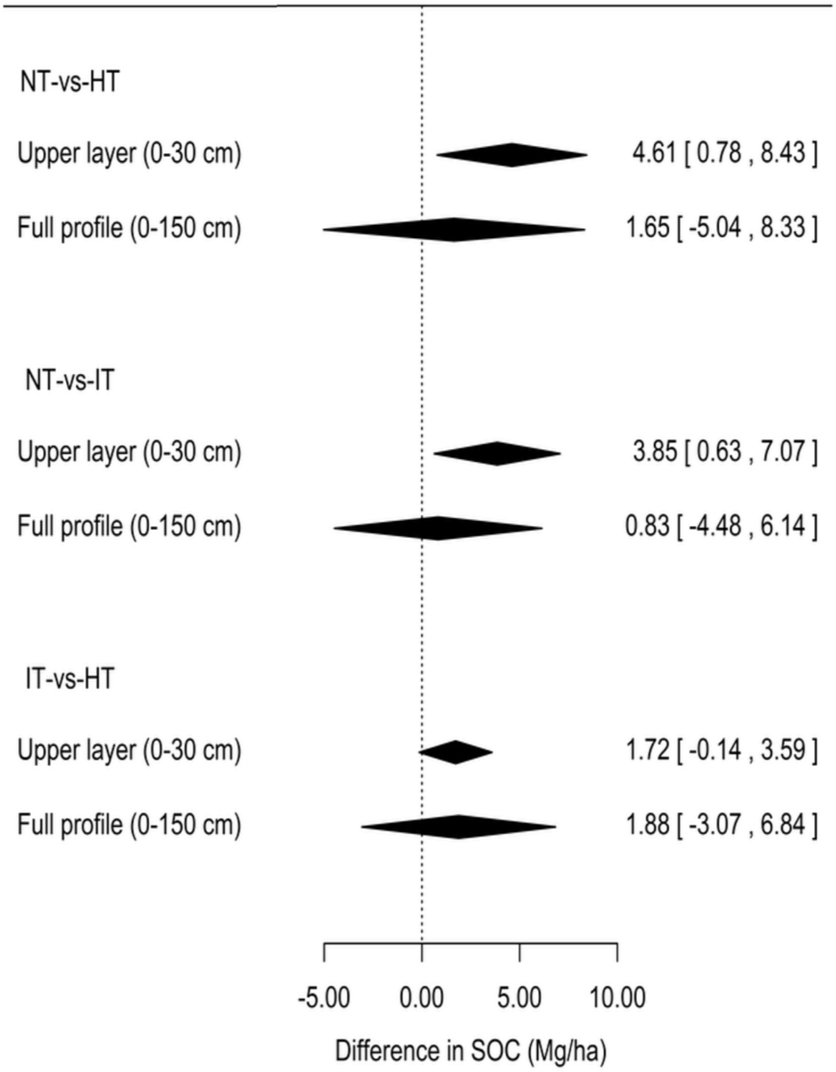


Fig A6 Proportion of bare soil on arable land (%), 2010 (Eurostat)

Table A1 of decline rates from 5 farms in Sweden with two different crop rotations and fertiliser levels. (Brady *et al.*, 2015)

Crop rotation	N kg/ha	Rate of change % per year
arable farm	0	-0.66
arable farm	50	-0.46
arable farm	100	-0.36
arable farm	150	-0.29
livestock farm	0	-0.46
livestock farm	50	-0.19
livestock farm	100	-0.31
livestock farm	150	-0.23

Fig A7 Metaanalyses of tillage and soil carbon (SOC Mg/ha)
(Haddaway *et al.*, 2017)



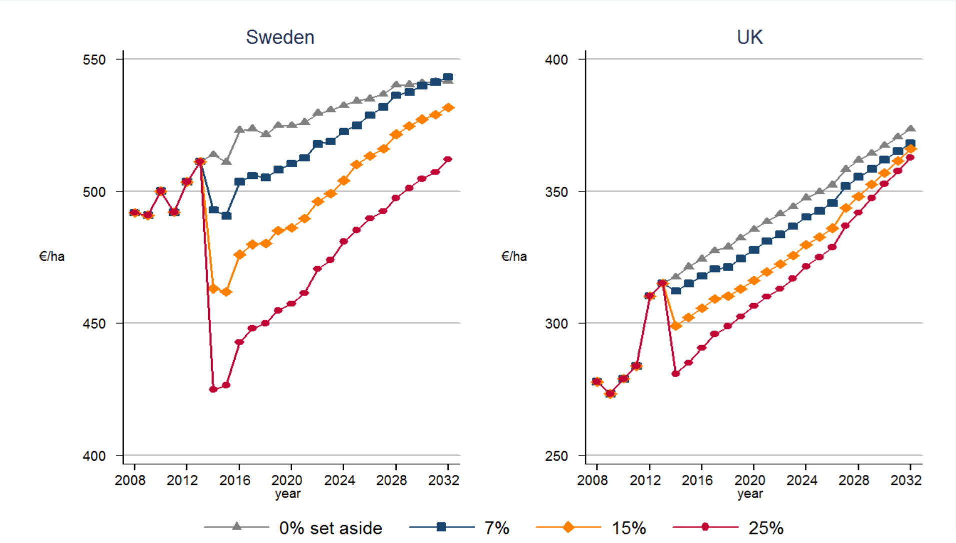


Fig A8 Simulations from a regional agent based model of farmers economy.

Scenarios of 0-25% set aside with grasses in the crop rotation, but with no income from the grass production. With a continuous increase of carbon the yields on the arable crops yields will increase and after more than 20 years compensate for the lack of income from the grass (Hedlund and SoilService, 2012).

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