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Barriers to and opportunities for the uptake of soil carbon management practices in European sustainable agricultural production

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Abstract

Soil carbon management practices are those that add and maintain organic carbon in the soil. These agricultural practices can potentially both contribute to climate change mitigation and increase the soil's resilience to physical and biological stresses. The paper draws on research findings from five regions across Europe to identify regionally-specific barriers to and opportunities for the adoption of soil carbon management practices. Data were derived from 50 interviews with policy-makers and advisers and 5 stakeholder workshops in Denmark, Italy, Hungary, Poland and Spain. Several barriers to the uptake of soil carbon management practices were common across all regions, however, regional variations were also identified highlighting the importance of understanding the context into which these practices are introduced. Key barriers related to existing biophysical conditions, lack of financial support, farmer knowledge and experience, and the quality of the advisory service. Opportunities included providing economic incentives, harmonising regulation, supporting long term thinking and planning for resilience and providing good quality advice. We conclude that in addition to persuasive mechanisms for encouraging the adoption of these practices, what is required is a more process-oriented approach that focuses on a series of experiential changes and fosters farmer learning through interactive models of communicative intervention.

Keywords: soil carbon management; barriers; opportunities; sustainable agriculture; climate change mitigation

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1. Introduction

Soils deliver multiple valuable ecosystem services, including the production of food, storage and filtering of water, and a habitat for different microorganisms (Ghaley, Porter, and Sandhu 2014). Increasingly, it is also recognised that soils can contribute to climate change mitigation and adaptation (Paustian et al. 2016, IPCC 2019). By adding to and maintaining organic carbon in the soil, it is possible to enhance carbon sequestration and storage. In a European context, systematic and long-term agricultural practices that incorporate organic carbon into soils through soil organic matter (SOM) might include cover (catch) crops (Ogle, Breidt, and Paustian 2005, Arrouays et al. 2002), crop rotations (Meyer-Aurich et al. 2006), residue management (Li, Frolking, and Butterbach-Bahl 2005, Lehtinen et al. 2014), reduced tillage operations (Ogle, Breidt, and Paustian 2005, Arrouays et al. 2002, West and Post 2002, Smith et al. 1997), fertilizer and manure management (Smith et al. 1997, Ladha et al. 2011).

In most cases, increasing SOM not only contributes to climate change mitigation, but also has the potential to deliver crop productivity benefits to farmers and to increase the soil's resilience to physical and biological stresses (Lal 2014). Future climate change is likely to affect soil properties and functions through increased incidences of, for example, flooding, salinization or drought (Gregory et al. 2015) requiring an increase in such resilience.

Given the potential for soils to increase carbon sequestration and storage and to improve soil resilience there is a policy interest in encouraging farmers to implement soil carbon management practices (SCMP), defined here as agricultural practices that make a net contribution to soil carbon compared to an initial baseline. Although the goal is primarily climate change mitigation, often adaptation is simultaneously achieved with these practices.

To date implementation of these practices (with a specific focus on carbon management) amongst the farming community in Europe has been slow and the reasons for this are not always evident (Merante et al. 2017, Sánchez, Iglesias, et al. 2016). Different bodies of economic and social-psychological literature frame the problem of uptake differently with most originating from an instrumentalist/persuasive tradition developed in agriculture (Leeuwis 2013). This tradition focuses on understanding why innovative agronomic practices are not being adopted, with an assumption that farmers behave rationally and that it makes sense for the farmer to adopt it ('pro-innovation bias') (Rogers 2010) and exploring barriers to adoption from the perspective of farmer behaviour and decision-making. Targeted interventions are developed to overcome these barriers through persuasive voluntary or regulatory measures (e.g. economic incentives and information).

More recently in intervention practice and theory, ideas regarding innovation have shifted from instrumental/persuasive models to interactive models of communicative intervention and a more process-oriented approach (Leeuwis 2013). This approach suggests that effective support and dialogue is required to increase the uptake of SCMP, which needs a good understanding of farmers' willingness and ability to engage with these practices and the social-economic and cultural influences on farmer behavioural changes. Whilst there has been research on understanding the interacting factors affecting the uptake of agricultural practices that reduce greenhouse gas (GHG) emissions (Smith et al. 2007), less attention has been paid to the barriers to uptake of management practices that increase soil carbon. Investigations with respect to farmers' behaviour and decision making in the context of soil carbon management are still relatively few (Dilling and Failey 2013).

The aim of this paper therefore is to present research findings from 5 regions across Europe that identify regionally-specific barriers to and opportunities for the adoption of SCMP that can contribute to climate change mitigation and are assessed as cost-effective. In the context of the paper, barriers refers to obstacles that impede the adoption of SCMP and opportunities to either on-farm enabling factors, or higher-level co-benefits, that facilitate the adoption of SCMP. This improved understanding of behaviour will highlight some distinct influences on farmer decision-making that can enable policy to provide more effective, regionally-specific, policy instruments and communication strategies to support the uptake of SCMP.

In this paper, we also explore the extent to which the characteristics of SCMP affect the innovation adoption processes. We consider the need not only for persuasion in encouraging adoption but also argue that what is required to encourage SCMP uptake is a more process-oriented approach that uses interactive models of communicative intervention.

2 Exploring factors that influence the uptake of SCMP

Different bodies of literature relevant to SCMP have explored factors influencing farmer's adoption of agronomic innovations and practices. These studies relate to climate change mitigation and adaptation, soil and crop management and agri-environment behaviour. This research has revealed that a range of interacting factors influence the adoption of new management practices and technologies (Mills et al. 2016, Feola et al. 2015, Long, Blok, and Coninx 2016).

Table 1 Review of barriers to adoption of farm management practices

Barriers	**Key contributing factors**	References
Agronomic/biophysical	-Change in farming system -Incompatibility -Complexity	(Ingram 2010, Kragt, Dumbrell, and Blackmore 2017)
Economic	-No relative advantage -Lack of financial benefits -Cost of adoption	(Kragt, Dumbrell, and Blackmore 2017, Wreford, Ignaciuk, and Gruère 2017, Dilling and Failey 2013, Smith and Olesen 2010, Dunn et al. 2016, Knowler and Bradshaw 2007)
Socio-cultural	-Socio-demographics -Farmer attitudes -Cultural capital	(Kragt, Dumbrell, and Blackmore 2017, Wreford, Ignaciuk, and Gruère 2017, Knowler and Bradshaw 2007, Townsend, Ramsden, and Wilson 2016)
Institutional/regulatory	-Lack of institutional support -Lack of advice/information -Lack of regulations/policy	(Kragt, Dumbrell, and Blackmore 2017, Wreford, Ignaciuk, and Gruère 2017, Smith and Olesen 2010, Knowler and Bradshaw 2007)

Most bodies of literature appear to highlight the importance of economic factors in influencing the uptake of new agricultural management practices, as identified in Table 1. According to Failey and Dilling (2010), if economic trade-offs between existing practices and the practices required to store carbon constrain profit, or at least do not enhance it, then they will not be adopted. This has led Dilling and Failey (2013 p. 5) to conclude that "Most farmers and ranchers would have no economic incentive to manage for carbon on their lands in the absence of policy or payment programs that would do so". Similarly, a number of studies looking at the adoption of conservation agriculture practices as a climate change mitigation activity suggest that factors influencing adoption from a farmers' perspective are based predominantly on its actual or perceived impact on profitability and crop productivity (Rochecouste et al. 2015, Wreford, Ignaciuk, and Gruère 2017).

One way of measuring the cost-effectiveness of a practice to reduce carbon emissions is through the use of marginal abatement cost curves (MACC). These indicate the cost of reducing an additional unit of carbon equivalent emissions given the adoption of certain mitigation options (Feliciano et al. 2014). MACC assessments have been produced for SCMP and identified a number of win-win practices that reduce greenhouse gas (GHG) emissions and save costs. However, as noted by Sánchez et al., (2016), despite the economic advantages of these win-win practices, they have not always been adopted (Sánchez, Iglesias, et al. 2016). This may reflect one limitation of MACC in that they assume that maximising economic benefits is one of the key objectives of farm decision making (Sánchez, Iglesias, et al. 2016). Similarly, other authors (Moran, Lucas, and Barnes 2013, Smith and Olesen 2010) have noted that climate change mitigation practices are not being adopted by farmers despite their adoption making good business sense. These findings would suggest that influences on farmer decision making in relation to farm management practices are more nuanced than simply economic barriers (Feliciano et al. 2014). Research has revealed that farmers have heterogeneous attitudes and motivations which affect their decision making, also as identified in the agri-environment literatures, other psychological and behavioural factors, such as self-identity and perceived behavioural control, also contribute to farmer decision-making (Mills et al. 2016).

Smith *et al.* (2007) and Smith and Olesen (2010) identified farm level policy and technological barriers to the implementation of GHG mitigation options in agriculture. They suggest that as well as economic barriers, there are biological/physical barriers, and social or political barriers to the uptake of GHG mitigation options on agricultural land. At the farm level, barriers might include lack of resources, lack of knowledge and skills, interference with regulations, property rights and financial constraints for investments. Wreford *et al*. (2017) in their comprehensive review of barriers to impede the adoption of climate-friendly agricultural practices at both the farm and sector and policy levels, also suggested that lack of information and awareness involved in climate change decision-making and risk management was an important barrier. A similar finding was reported by Kragt *et al*. (2017) in Australia, where lack of information was a key barrier to the adoption of carbon farming practices, as well as uncertainty about the impact on the farm business, high costs and incompatibility with current farm management strategies.

Other studies have identified barriers, other than economic ones, which affect the adoption of reduced tillage. Ingram (2010), for example, noted that the knowledge intensive nature of reduced tillage practices was a constraint to both uptake and continued use. Whilst Townsend et al (2016) identified social/cultural barriers, such as resistance to a long-standing tradition of using a plough, or concern about "untidy" appearance of fields that can be perceived as poorly managed.

Looking at the adoption of conservation agriculture (which comprises a set of SCMP), Knowler and Bradshaw (2007) identified the following factors as influencing adoption: farmer characteristics, such as age, experience and education; farm biophysical characteristics, such as farm size, rainfall; farm financial/management characteristics, such as land tenure, farm income/profitability, and labour source; and exogenous factors, such as information, government policies and social capital. They also suggest that "there is evidently a need to identify those factors beyond just farm finances that explain adoption (or, most importantly, non-adoption)" (Knowler and Bradshaw, 2007 p29).

However, they also found that there were few if any universal factors that explained the adoption of conservation agriculture. Instead, factors influencing adoption of conservation agricultural practices were locally or regionally specific. Similarly, Sanchez (2016) and Merante (2017), also demonstrated that levels of uptake of new SCMP are highly context specific, at a regional and often even farm level, depending on the local biophysical, social and economic conditions. The aim of this paper, therefore, is to identify regionally-specific barriers to and opportunities for the uptake of SCMP.

These different ideas from the literature were brought together to provide an analytical framework to identify not only the economic barriers and opportunities to taking up SCMP, but to extend this analysis to any technical, social/cultural and policy barriers affecting implementation of all SCMP across different biophysical and geospatial zones across Europe.

3. Methods

Context

The paper mainly draws on the results of an EU-funded research project (SmartSOIL), which aimed to identify and promote beneficial SCMP. The paper was then informed by stakeholder engagement research undertaken in 5 case study NUTS 2[2] regions across Europe, that although cannot be considered representative of all EU agricultural territory, can, through their diversity from a biophysical, productive and socio-economic perspective, reflect a limited but common EU farms reality (see Table 2). Case study regions were selected by project partners using national expert knowledge to represent different bio-geographical (farming systems, soil type, SOC content, risk of soil carbon loss) and socio-economic contexts across Europe. Characteristic data for the case studies were collected by the project partners and supplemented with Eurostat data (2010).

Table 2 Details of case study regions

NUTS 2 Region/ Biographical region	*Avg. farm size/ Farm holdings >50ha/ % owner occupied	*Dominant production systems
Denmark: Region Zealand/ Continental	61 ha 32% 72%	Cereal production and livestock, primarily pigs
Hungary: Közép-Magyarország/ Pannonian	5 ha 1% 36%	Cereals with small to large dairy and small mixed farming (dairy, poultry and pigs)
Italy: Tuscany/ Mediterranean	10 ha 3% 75%	Cereals, olives and grapes
Poland: Mazowieck/ Continental	7 ha 1% 89%	Small/medium scale cereal production and medium scale and high input orchards
Spain: Argon/ Mediterranean	18 ha 6% 79%	Cereals, olives and grapes

*Eurostat data, 2010

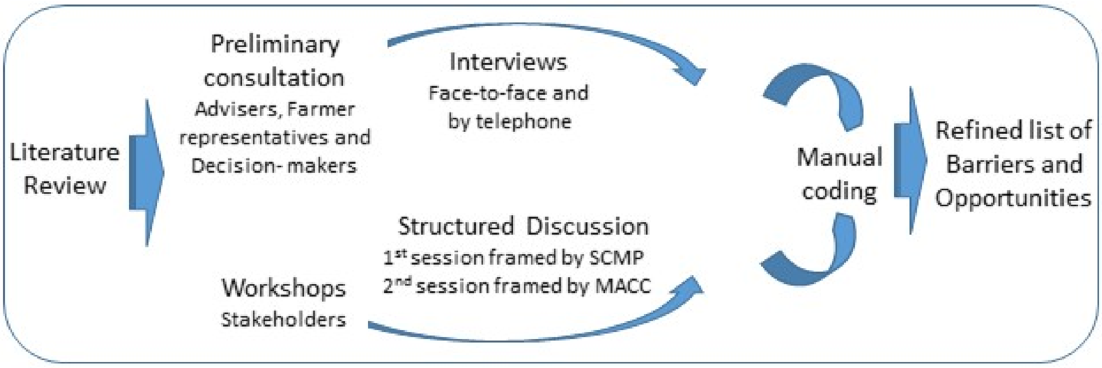
[2] Nomenclature of Territorial Units for Statistics (NUTS) is a European Union geocode standard for referencing the subdivisions of countries for statistical purposes. NUTS 2 are defined as basic regions for the application of regional policies.

For the purposes of the project, the key SCMP that were identified were: catch (cover) crops, crop rotations, residue management, reduced tillage operation (and conservation agriculture as a combination of these three), fertilizer and manure management (based on nitrogen and carbon management). These were selected by drawing on an extensive review of research, project experimentation and project partner expertise (Wosten and Kuikman 2014). There is not space here to provide a comprehensive account of how these practices can potentially impact carbon sequestration and how this potential varies regionally, but for such a discussion see Merante *et al*. (2017), for example.

Methods

Data were collected through a preliminary consultation followed by stakeholder workshops in each of the 5 case study regions as depicted in Figure 1. The methodology is underpinned by the analytical framework (Table 1) developed from the literature. This is not a systematic analysis since the literature specifically referring to barriers to adoption of soil carbon management practices is limited, however this narrative review provides a good basis for framing data collection in the case studies and was used to structure the interview schedules together with expert knowledge from the project partners.

Figure 1 Stakeholder engagement: data collection methods



3.1 Preliminary consultation

Project case study partners, themselves linked to agronomy and advisory institutions, used their professional networks and existing relationships to identify and purposely select a range of interviewees for a preliminary consultation.

Fifty face-to-face or telephone interviews and in one case (Spain) a group discussion were conducted with selected agricultural advisers (from public extension and commercial services), farmer representatives and decision-makers in the five case study regions. These were selected as they could provide an informed and broad view about farming activities in the respective case studies, as opposed to individual farmer's perspectives, which would have been too narrow. Furthermore, project resources did not allow for a large farmer survey. Farmer representatives were farmers who had a position in a local agriculture chamber, co-operative or union and could act as a spokesperson for a larger number of farmers. The advisers worked at the national or regional level and included arable crop advisers as well as those who worked in public good initiatives (e.g. soil protection, diffuse pollution, climate change mitigation programmes). Decision-makers were selected for their focus in the area of soil conservation, diffuse pollution or mitigation of climate change.

Table 3 Preliminary consultation interview and workshop participant numbers

	Preliminary consultation interviews			
	Adviser no.	Farmer reps.	Decision-makers no.	Total interviews/workshop participants
Denmark	4		3	7
Hungary	3		2	5
Italy	3		6	9
Poland	13		5	18
Spain	6		5	11
	Workshop participants			
Denmark	7		1	8
Hungary	17		3	20
Italy	2	3	2	7
Poland	14	3	4	21
Spain	4	5	1	10

A national researcher in each case study conducted the face-to-face interviews using a semi-structured template. Different interview schedules were developed for decision-makers and advisers/farmers, respectively and were based on the analytical framework which identified the most relevant issues to farmer uptake of soil management practice for each stakeholder type. Seven pilot interviews were conducted in UK and minor changes were made to the format, length, and question type.

The aims of the interviews were to identify:

- the current awareness in the farming community of soil carbon management and the extent to which associated practices were implemented.
- the barriers to, and incentives and advice for, the uptake of practices by farmers that can enhance soil carbon stocks.
- the policy context for promoting the management of soil carbon with a focus on the practices that can potentially enhance soil carbon.

Numbers varied, but on average ten interviews were conducted in each of the five countries (see Table 3). Following data analysis, the results for each case study region were summarised and further discussed and validated at the stakeholder workshops.

3.2 Participatory stakeholder workshops

National researchers in each case study also conducted participatory stakeholder workshops. The researchers were provided with detailed guidelines, pre-prepared slides and a report template in order to standardise the workshop content, format and reporting. In addition Marginal Abatement Cost Curves (MACC) were prepared for each case study, as described in Sánchez *et al.*, (2016). These MACC, as explained in more detail elsewhere (McVittie et al. 2014), were calculated by measuring the change in the typical gross margin related to the implementation of each SCMP management practice and crop and the abatement effect in GHG with the implementation of the practice.

Case study partners, using their local knowledge, identified workshop participants (advisers, farmers' representatives and decision-makers). Interviewees previously involved in the preliminary consultation were invited as well as new stakeholders, including farmers, considered to have relevant experience and understanding of farming and/or soil management in the region. The number of participants in each workshop ranged from 7-21 (see Table 3).

During the first workshop session, participants were presented with summarised data from the interviews and data on typical cropping systems, SCMP and effects on soil carbon which framed the discussions and were validated by participants. In the second session, MACC diagrams showing the cost effectiveness of different measures/crop combinations in increasing soil carbon in terms of changes in gross margin, were presented (see example in Figure 2). These MACC diagrams were used to initiate a discussion about potential win-win practices and the barriers and opportunities with respect to their implementation. In particular, the participants were asked to consider the possible barriers and opportunities to implementation of the SCMP identified as promising by the MACC under the following broad headings:

- technical - related to specific crops or systems (e.g. rainfed vs irrigated, spring vs winter cropping)
- agronomic (e.g. cultivations times, disease issues)
- environmental (e.g. climate, growing season)
- economic (e.g. fixed costs, need for new equipment)
- social (e.g. land tenure patterns, social perception by other farmers, conflict with 'traditional' approaches)

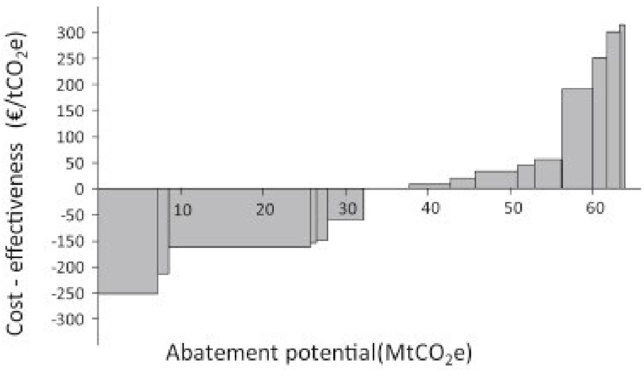


Figure 2 A schematic example of a MACC where the mitigation practices (bars) are ranked in order of decreasing cost-effectiveness from left to right. The MACC plots the abatement potential that could be achieved by practices that generate negative abatement cost values (i.e., incur cost-savings) and practices that generate positive abatement cost values (i.e., incur a positive cost) (Source: Sánchez, 2016b)

The level of consensus about the significance of the barriers was evaluated during the workshops. The range of case studies with their different contexts and institutional settings enabled an exploration of how influential these different barriers and opportunities were in the adoption of SCMP.

Interview and workshop data were collected as audio recordings and written notes. Interview data were transcribed and translated into English by the national researchers, whilst workshop data were used to prepare a workshop report that was then translated into English. Analysis of all interview transcripts and workshop reports was then undertaken by the case study coordinator through manual coding according to recognised methods (Ryan and Bernard 2003), identifying in-depth the key barriers and opportunities to the uptake of SCMP in each case study. The technical and agronomic and environmental (biophysical) barriers were merged into one category.

4. Results

Interviews

Analysis of the interviews identified the SCMP promoted and the barriers to their uptake in each of the 5 case study regions (see Table 4). The analysis confirmed that barriers to SCMP adoption fell within the categories identified in the framework.

Table 4: Interview results of practices promoted and barriers in case study regions

	Practices promoted and barriers
Denmark Sjælland	*Promoted*: Soil management is an integral part of an overall crop production strategy aimed at gaining the best economic output, and soil carbon management is a part of this. Practices, promoted as part of an overall approach to good soil management, include: planting catch crops, crop rotations, residue management, managing perennial grasses, manure and fertilizer management and reduced tillage. *Barriers*: Lack of visual evidence that these practices benefit soil health, are cost effective and enhance crop yield in the long-term.
Hungary: Közép-Magyarország	*Promoted*: Advice on soil management practices focuses primarily on degradation and nitrate pollution issues. There is an emphasis on reducing greenhouse gas emissions and fostering bio-energy production and use in the climate change mitigation context. Practices, promoted as part of an overall approach to good soil management, include: appropriate crop rotations, organic manure input, restricted management options on steep slopes, reduced-tillage and grass or mulch layers in orchards. *Barriers*: Innovative practices are subsidy driven. Farmers are mostly concerned about complying with regulations. Commercial advice conflicts with advice on soil management concerned with the supply of ecological services (public goods).
Italy: Tuscany	*Promoted*: Practices in cross compliance measures which can contribute to improving soil carbon in the soil: minimum tillage, stubble management, green manure, crop rotation, and minimum soil cover and terracing maintenance. *Barriers*: Farmer reluctance to take up unfamiliar practices and to integrate them into

	consolidated farm management systems. New practices are not supported by practical evidence of effectiveness.
Poland: Mazowieck	*Promoted*: Practices promoted relate to cross compliance requirements and include: cover crops, crop rotations and manure and fertilizer management. *Barriers*: Farmer (and administration) awareness of environmental/climate threats is low. This, together with low profitability of the agricultural sector, impedes implementation of soil management practices. Moreover, many farmers have limited education; and the quality of (free) state advisory services is inadequate.
Spain: Andalucía	*Promoted*: Practices, promoted as part of an overall approach to good soil management, include: reduced tillage, erosion safe cultivation, catch crops, fallow fields, residue management, manure and fertilizer management, crop rotations and extensive farming, pasture, and organic farming. *Barriers*: Lack of consensus on 'best practice' in Mediterranean/semi-arid climates. Measures exist but there is no process for tailoring them to farms. The high number of tenant occupied farms is a barrier to uptake.

When further examined in the workshops with reference to the MACC assessment, it was clear that SCMP assessed as cost effective were subject to technical/agronomic, economic, and social/cultural barriers and institutional barriers. The following results on the stakeholders' perspectives on barriers to uptake of specific SCMP are synthesised from both interviews and workshops, identifying the level of consensus across the regions.

4.1 Barriers to uptake

Zero/Minimum tillage

Zero/minimum tillage was identified in the MACCs as a potential cost-effective (win-win) practice for the case studies in Denmark, Hungary, Italy (minimum tillage for maize and sunflower and zero-tillage for barley) and Spain (on barley (irrigated and rain fed). However, as identified in Table 5, a number of barriers to implementation were identified in these regions.

Table 5 Barriers to update of zero/minimum tillage in 5 case study regions

	Level of consensus		
Barriers	**High**	**Medium**	**Low**
Technical/ Agronomic	• Lack of equipment - new machinery required (HU, IT, PO, ES)	• Perennial weed problems - need for weed control, particularly on organic farms (DK, IT, ES) • Small holding size restricts investment potential (HU, PO, ES)	• Cold climate problematic for germination/crop growth (DK) • Crop yield uncertainties in terms of quality and quantity (IT) • Higher organizational /logistical complexity: may require changes in the management system (IT)
Economic	• Investment requirements. Excessive costs of new machinery (HU, IT, PO, ES)	• May imply higher costs for weeding (IT, ES) • Potential risk of crop failure. Income uncertainties (DK, IT)	•Need for crop type changes to maintain high yields (DK) •New practice requires time to integrate into the management system (IT)
Socio-cultural	• Conventional system of tillage strong	• Lack of knowledge and of adequate technical skills	• Limited learning capacity (HU) • Lack of willingness and

	tradition, particularly for older farmers, resulting in difficulties in accepting a practice that is "outside" of the knowledge and experience (HU, IT, PO, ES)	and information about the practice and its benefits. (HU, IT)	cooperation skills (PO) • Farmers need to see the practice more extensively implemented in surrounding farms (ES) • Aesthetic value is lost (fields look 'messy') (DK)
Institutional		• Poor advice support. Lack of specific regional agriculture services which "properly" inform and train farmers (HU, IT) • Lack of farmer awareness due to insufficient dissemination /communication of the benefits (IT, PO) • Lack of demonstrations and real life examples of the practice and its potential benefits (IT, PO)	• Controversial technical advice (HU)

There was a high level of consensus across the case studies (HU, IT, PO, ES) that farmers lacked the specialist equipment and financial resources to invest in the machinery required to implement minimum tillage practices. Smallholdings, in particular, which are predominate in the Italian, Polish and Spanish case study regions, may not be in a financial position to invest in such new machinery. In addition, farmers are often unwilling to invest in new practices where they were uncertain about the results. For example, a need to see the practice more extensively implemented in surrounding farms was expressed in Spain. According to the stakeholders, some farmers perceived the practice as technically difficult and therefore only attractive for the very skilled or dedicated farmers. Specific concerns related to germination/crop growth; perennial weed problems; and a lack of appropriate existing technology to control weeds on organic farms (DK, IT, ES).

In addition, there was a consensus across CS stakeholders of a resistance to change traditional cultivation practices, particularly amongst older farmers who were reluctant to change to tillage practices that were outside their knowledge and experience and where learning capacity to acquire new knowledge and skills was limited. Cultural resistance due the negative aesthetics effects of 'messy' fields was also identified as a barrier in Denmark.

In some regions (HU, PO and IT) limited advice and support on minimum tillage was identified as a barrier. Also poor farmer awareness existed due to insufficiencies in the regional agricultural services to support and communicate the benefits. In particular, there was a lack of tillage demonstrations and examples of practices and its potential benefits.

Catch/cover crops (CC)

Cover crops were identified in the MACCs as a potential cost-effective (win-win) practice for the case study in Spain on irrigated maize. As shown in Table 6, barriers to uptake were identified in all five case study regions.

Table 6 Barriers to the uptake of catch/cover crops in 5 case study regions

	Level of consensus		
Barriers	**High**	**Medium**	**Low**
Technical/ Agronomic		• Climatic conditions - in rainfed systems in Spain a risk of decrease in soil moisture, whilst in Poland autumnal drought can complicate CC sowing and cold conditions in Denmark can make CC establishment difficult (ES, PO, DK) • Time conflict of harvesting vs. sowing the cover crops (HU, IT) • Greater complexity in managing crop rotation and less flexibility in choosing winter crops vs. spring-sown crops (DK, IT) • Concerns about water competition between CC and spring crops (PO, ES)	• CC prevent efficient mechanical weed control (DK)
Economic	• Increased costs due to seeds and extra field operations (HU, IT, PO, ES, DK)		• Crop replacement cost can be high (winter wheat replaced with spring barley) (DK) • No demand for cover crop products (PO)
Socio-cultural	• Lack of awareness and understanding of the benefits of CC (IT, ES, DK, PO)		
Institutional		• Low quality advice and training adapted to regional conditions (PO, ES) • Insufficient communication of benefits to farmers (IT, DK)	• CC are mandatory and unpopular (DK)

There was a high level of consensus across all case studies that the increased costs of establishing and managing cover crops, including the costs of seeds and additional field operations, acted as a barrier to uptake. This economic barrier was exacerbated by the potential need to replace winter wheat with spring barley (DK) and the lack of a demand for cover crop products (PO).

A further common view across all case studies was the lack of awareness and understanding of the benefits of cover crops, exacerbated for some case studies by insufficient communication of the benefits of this practice (IT,DK) and the low quality of available advice and training which is adapted to regional conditions (PO, ES).

Regional climatic and environmental conditions can have an impact on the uptake of catch/cover crops. For example, the cold climatic conditions in Denmark in general can make catch crop establishment difficult, whilst in Mazovia, Poland autumnal drought can affect the sowing of catch crops. Technical difficulties were also expressed in relation to the timing of cover crop establishment, including a lack of time after harvest to accommodate cover crops and difficulties in successful establishment due to germination problems (DK, HU, IT). The potential risk of water and nutrient competition was identified as an important agronomic barrier to implementing cover crops, especially in rain-fed systems in arid areas (PO, ES) and restrictions on efficient mechanical weed control and reduced flexibility in choosing winter crops vs. spring-sown crops (DK).

Residue management

Residue management was identified in the MACCs as a potential cost-effective (win-win) practice for the case studies in Hungary, Italy (durum and common wheat) and Poland. However, as Table 7 shows the practice has some barriers associated with it that affects implementation.

Table 7 Barriers to the uptake of residue management in 5 case study regions

	Level of consensus		
Barriers	**High**	**Medium**	**Low**
Technical/ Agronomic			• Sometimes need for external fertiliser inputs before incorporation of residues (IT)
Economic		• Loss of income from not selling straw (DK, HU, ES)	• Additional farm operations (e.g. grinding crop, removing the residue) (ES)
Socio-cultural		• Lack of up-to-date knowledge about practice (HU, ES)	• Stubble burning seems to be an effortless practice for farmers (ES)
Institutional			• None; regulations have helped to implement residue management (DK)

There was a moderate level of consensus across the case studies about the loss of income from not selling straw acting as a barrier to uptake of residue management. In some countries, straw can have a high economic value (DK, ES, HU), for example, local mushroom growers in Central Region, Hungary will pay well for straw and even bale it. Furthermore, the extent to which the costs and prices associated with a practice will fluctuate, changing with market demands, so for example, whilst crop residues may currently have little economic value in some countries, the increasing use of biodigesters means straw may start to have a value threatening its contribution to soil organic matter. In the Polish case study region, residue management is a common practice and considered a cost effective and barrier-free practice. However, in Andalucia in Spain, in general the burning of crop residues has preference over incorporating the residues into the soil.

Adding legumes to crop rotation

Adding legumes to crop rotations was identified in the MACCs as a potential cost-effective (win-win) practice for the case studies in Hungary and Poland. A number of barriers were identified as affecting implementation (see Table 8).

Table 8 Barriers to the uptake of adding legumes to crop rotation in 5 case study regions

	Level of consensus		
Barriers	**High**	**Medium**	**Low**
Technical/ Agronomic		• Soil unsuitability (HU) or climatic unsuitability (ES)	• Potential risk of crop failure (DK)
Economic		• Lack of market for legumes due to reduced livestock production (HU, PO) or competition with soybean imports (ES)	• Costly to have legumes as CC, they need to be grown in addition to mandatory CCs (DK) • Costs of higher management requirements and inputs (ES)
Socio-cultural			• Legumes not accepted as mandatory CCs (DK) • Social discredit of the practice in the past (ES) • Lack of experimental evidence on the N2O net emissions from the legumes application (ES)
Institutional			• Lack of training and capacity building for the farmers (ES)

There was moderate consensus across the case studies that the lack of a market to sell legumes was a particular barrier for growing legumes in a crop rotation. This was especially the situation in the Hungary and Poland case studies, where increased specialisation and decreased livestock production has reduced the demand for legumes and in Spain, where legumes face competition from soybean imports. In Mazovia, Poland, although farmers are aware of the benefits of legumes, they were considered uneconomic to grow without subsidies. Similarly, in Spain legumes were considered to increase costs through higher requirements in management and inputs application.

Specific agronomic conditions were identified as a barrier to growing legumes. For example, in arid conditions in Andalucia, Spain with precipitation less than 400mm/year, legumes in crop rotations do not grow well, nor do they grow well in the sandy soils of Central Region, Hungary. Also in Denmark, concerns were expressed about the increased risk of crop failure when using legumes as a catch crop.

In Denmark, because legumes are not accepted as legal catch crops (if the farmer wants to apply legume-based catch crops, they need to be grown in addition to the mandatory catch crops) this discourages farmers from cultivating legumes. Cultural barriers exist in Spain as growing legumes has been discredited in the past. Furthermore, there is uncertainty and a lack of experimental evidence on the N_2O net emissions from growing legumes.

Manure and fertiliser management

Manure and fertiliser management was identified in the MACCs as a potential cost-effective (win-win) practice for the case studies in Hungary and Spain (for irrigated maize). As identified in Table 9, a number of barriers to implementation were identified in the case study regions.

In both Mazovia, Poland and Central Region, Hungary, a reduction in livestock systems (or a switch from barn to slatted floor rearing) in the regions has reduced supplies of animal manure, making it unavailable or uneconomic to apply. Consequently, farmers lack the equipment needed to spread manure, which is costly to purchase. Also in Spain, it was suggested that compared to chemical fertilisers, manure application can produce lower yields in high productivity areas and reduces the ability to produce standardised products. Also compared with chemical fertilizers, manure management involves higher organisational complexity due to the transport, management and spreading of the manure.

Table 9 Barriers to uptake of manure and fertiliser management in 5 case study regions

	Level of consensus		
Barriers	**High**	**Medium**	**Low**
Technical/ Agronomic		• Higher organizational /logistical complexity with the need to purchase, transport, manage and spread the manure (IT, ES)	• Difficult management in retrieving, purchasing, transporting, managing, spreading manure (IT)
Economic		• Lack of manure availability makes practice uneconomic (HU, PO, ES) • Higher costs due to increased labour input in transporting, managing and spreading the manure (IT, ES	• Lower yields in high productivity areas (ES) • Need to standardize the product (ES)
Socio-cultural		• Odour problems of manure application near urban or population areas or on farms which provide tourism services (IT, ES, PO)	• The low acceptance by the farmers due to problems or impacts in neighbouring farms (ES)
Institutional		• Restrictive rules for manure spreading and transportation (IT, HU)	• Compliance with EU Nitrates Directive (HU).

Restrictive legislation for manure application was mentioned as a barrier in some case studies (HU, IT, ES). For example, compliance with Nitrates Directive means that in Hungary risk averse farmers do not apply any manure because of the risk of being penalised. A socio-cultural barrier identified in the case studies in Italy and Spain, Hungary related to odour issues with manure application, affecting farm tourism activities and local populations.

4.2 Barriers Overview

Whilst some consensus was identified across regions, a clear finding was the regional variations in the barriers and opportunities for the uptake of soil carbon management practices and the importance of understanding the context into which these practices are introduced.

Technical/agronomic barriers
Overall, the findings indicate that the biophysical environment in which the farm operates can limit the uptake of SCMP. The soil context can also influence which practices can be taken up. For example, the sandy soils of Central Region in Hungary are not suitable for growing legumes. Other technical concerns were related to weed control and the increased organisational and logistical complexity of operationalizing some of these practices.

Economic barriers
Concerns about income uncertainties from introducing the new soil carbon management practices were identified as a common barrier to uptake but from different perspectives in the regions studied

but from different perspectives. Farmers, particularly those who are risk adverse, are looking for more assurances about the income potential of these practices. There was broad consensus across all case studies that a lack of financial incentives or subsidies was a barrier to the uptake of SCMP. The subtleties of economic motivations for management decisions were also revealed differentially in different regions. Profit/gross margin was considered more important than maximising yield while resilience was considered of low importance in all workshops.

Social/cultural barriers

The results have highlighted that farmer decision-making in relation to SCMP is not influenced by economic and technical decisions alone and that other factors play a part in decisions about adoption. Our findings support those of Feliciano *et al.* (2014) that social and cultural factors are as important a barrier to uptake of climate change mitigation practices as agronomic and economic factors.

A resistance to change from traditional practices was identified in the small farms of the Italian and Spanish case studies where, for example, the winegrowers were reluctant to substitute the present system of removing weeds from between the rows of vineyards with cover crops in case of failure in dry years. Also, a reluctance to change was evident amongst the older and conservative small-scale farmers of the Hungarian, Italian and Polish case studies who used traditional practices, that were familiar and relatively risk free, such as deep ploughing. This resistance of older farmers and small farms to adopt new practices is not unique to SCMP and has been identified as a barrier for the uptake of other sustainable land management practices (Wreford, Ignaciuk, and Gruère 2017, Karali et al. 2014, Sánchez, Álvaro-Fuentes, et al. 2016). In Poland, an important barrier was the lack of willingness and readiness of farmers to cooperate, owing mainly to historical and socio-cultural reasons (Bijman et al. 2012). This prevents the joint purchase of machinery (e.g. for zero/reduced tillage cultivation) by several small farm owners which would overcome the economic barrier hindering the introduction of this cultivation technique.

Some of the workshops discussed the importance of profit to the farm business, with shorter term business perspectives negatively impacting sustainable soil management. Examples include: “land speculators” in Central Region, Hungary who aim to minimize investments/costs; small farmers in the case studies in Poland, Hungary and Spain (who are struggling to remain profitable or for whom the farm is not the main source income) who tend to react only to current market trends, rather than undertake long-term production planning. A further structural issue reported related to land tenure. It can take several years before the economic benefits of SCMP are realised which does not always correspond with the short-term outlooks of rented farms. Short terms tenancies and the use of farm contractors are often incompatible with the long term planning needed for SCMP to be effective

Institutional/Regulatory barriers

Lack of institutional support in the form of context specific advice and information was a clear barrier mentioned in all regions. Appropriate knowledge exchange and information available to farmers to explain the benefits of SCMP and to demonstrate these benefits through real-life examples was lacking. For example, in Hungary advice on soil management practices focuses primarily on degradation and nitrate pollution issues, rather than soil carbon issues and commercial advice can contradict good soil management advice. There was limited information to explain the benefits of SCMP and to demonstrate the benefits. Also, participants in some regions (in particular Hungary, Poland, Spain and Italy) felt hampered by poor quality regional advisory services to deliver these messages.

4.3 Opportunities for uptake

A number of opportunities to encourage the implementation of soil carbon management practices were identified. Dominant amongst these was the option to provide incentives to encourage uptake. These could take different forms, for example, subsidies to purchase necessary machinery or inclusion of these practices as part of agri-environment measures or some sort of economic incentive related to GHG quota.

Adapting legislation to encourage SCMP uptake was also identified as an opportunity. For example, in relation to adding legumes into crop rotations, a change in the national regulations in Denmark so that legumes are acceptable as a catch crop would result in a wider uptake of legumes. Also in Italy further uptake of manure application would be encouraged if there were less restrictive rules for spreading and transportation of manure and policies encouraged mixed farming systems.

It was suggested that two of the main conditions that need to be met to ensure a long-term perspective to soil management is improving the economic prospects of farms and ensuring the presence of a stable agricultural policy, highlighting the importance of a wider enabling environment.

With an increase in extreme weather as a result of climate change, it was suggested there might be an opportunity to promote the resilience benefits of SCMP, such as improving soil water capacity, to encourage long-term planning. For example, mutual benefits or synergies from SCMP could be promoted, especially as in some case studies, such as Hungary, 50% of the soils in the region are climate sensitive.

A consensus across all case studies was that opportunities should be taken to improve existing advisory provision and to establish real-life demonstrations of the practices in operation to demonstrate the economic benefits over the longer term and how these practices can be integrated into existing management systems. In particular, it was suggested that advice needs to focus on identifying how practices can maximise profits and gross margins as this was identified in all countries as the main driver of farmer decision-making. Maximising profit did not always equate with increasing yield. In Mazovia, Poland, for example, farmers are not striving to maximise yields for fear of experiencing difficulties in selling the product.

5. Discussion

SCMP have the potential to both contribute to climate change mitigation and increase the soil's resilience to physical and biological stresses (Paustian et al. 2016, Smith et al. 2007, Lal 2014). As there is a policy imperative to encourage such 'climate-friendly' and resilience-building practices, an understanding of any barriers to opportunities for uptake is necessary.

Our research findings across five European countries indicate that the reasons for a lack of uptake of SCMPs are complex. Approaches that simply transfer knowledge about SCMPs to encourage adoption or rely on economic incentives alone may fail. We have found that even when there are economic advantages to the farmer in adopting SCMP, as demonstrated by MACC, there are also currently agronomic, technical and social/cultural barriers which discourage the uptake of these practices. These barriers range from the farm level to institutional and market level and can differ across the regions of Europe.

Although some consensus on the barriers to uptake of SCMP were identified across the regions, the results also highlighted the regional variability in the barriers to uptake and the importance of understanding the context in which they are implemented. For example, the local value or availability of straw or manure can influence decisions in relation to residue or fertiliser management, or the local soil or climatic conditions can influence the implementation of certain practices. The findings clearly indicate that any incentives to encourage the uptake of SCMP cannot be implemented at an EU-wide level, rather regional-wide policies, including subsidies and communicative interventions, need to be adopted, that are tailored to overcoming specific local and regional agronomic and technical and social and cultural barriers to SCMP uptake. Similar conclusions have been reached in relation to encouraging the uptake of agri-environmental or climate change practices in agriculture (Mills et al. 2016, Wreford, Ignaciuk, and Gruère 2017).

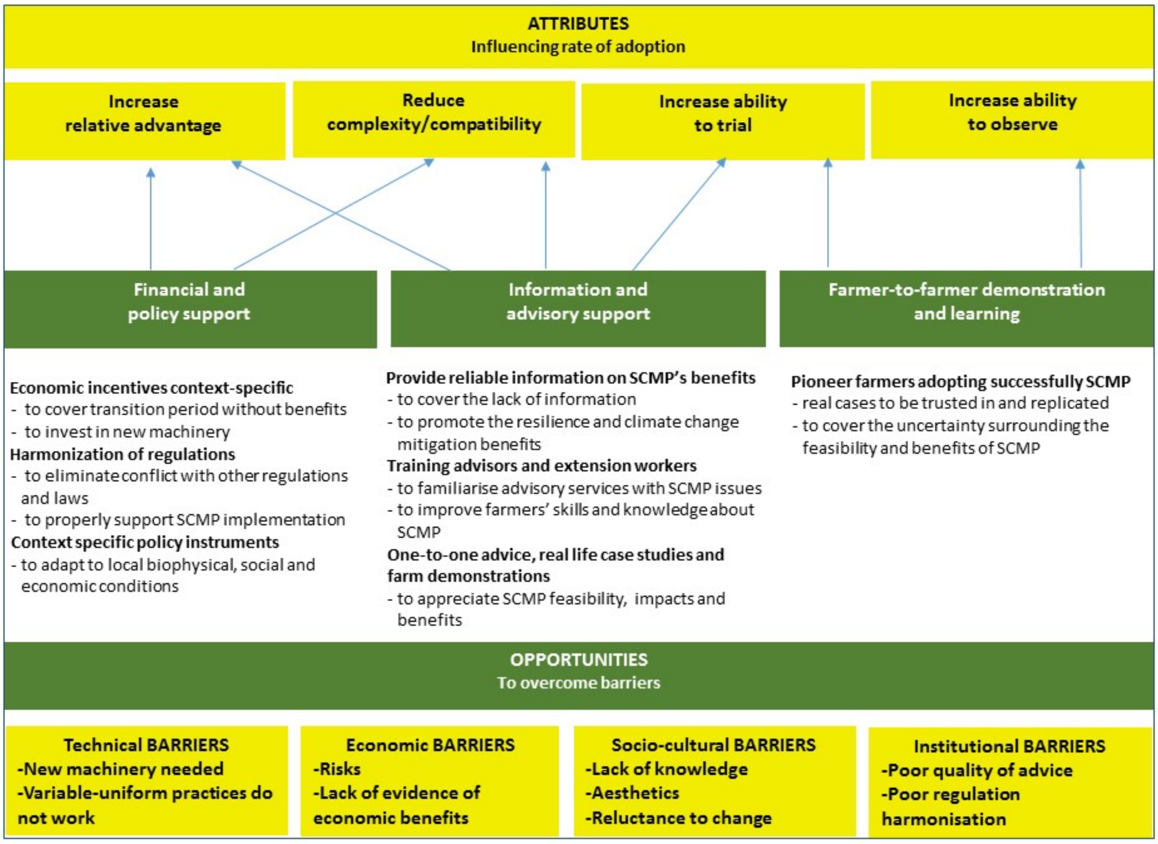
Key barriers that appear to influence the uptake of SCMP relate to existing biophysical conditions, lack of financial incentives, farmer knowledge and experience, and the quality of the advisory service. These barriers need to be taken into account in developing management recommendations and policy and advisory programmes to increase carbon within the soil.

Key themes emerged out of the discussion of opportunities, namely, providing economic incentives, harmonising regulation, supporting long term thinking and planning for resilience and providing good quality advice. Collectively these can be considered within a framework that allow us to consider how to enable and encourage adoption of SCMP

Rogers (1983) based on a review of adoption rates for different innovations amongst commercial farmers in the US, suggested that variance in rates of adoption of a new practice is explained by five attributes, namely: relative advantage (perceived as better than the practice it supersedes), compatibility (perceived as being consistent with existing values, past experiences and needs) , complexity (perceived as difficult to understand and use), ability to trial (can be experimented with), and ability to observe (results visually available to others). Taking these five attributes of a practice that can influence the rate of adoption and the study findings, we identified, in Figure 3, a number of opportunities for increasing the uptake of SCMP.

Relative advantage. Even though the long-term economic advantage of SCMP as win-win practices have been demonstrated (see for example Sánchez, Iglesias, et al. 2016), they were not always perceived by the case study farmers as practices for reducing risk or securing viability. This was in part because the relative advantage of these practices may only be realised in some future, unknown time. Consequently, economic incentives may be required to encourage uptake in the short-term, particularly for subsidising machinery requirements or other inputs costs. However, our findings suggest that decisions to offer incentives to encourage uptake are likely to be context-specific due to socio-cultural differences. In some countries, for example in Hungary and Poland, we identified a dependency culture on subsidies where financial incentives are more likely to be required to encourage uptake. In other countries, such as Spain, respondents suggested that demonstrating how practices can potentially improve farm profitability and productivity are equally as important as financial incentives for encouraging uptake (Ingram et al. 2014). Similarly, an increased coherence of the regulatory framework to support SCMP may be required. We identified, for example, regulations which conflict with the goals of SCMP, such as the rules on manure application and transportation which may require adapting.

Figure 3 Opportunities to foster the uptake of SCMP



The relative advantage that SCMP offered compared to existing practices was also not always apparent due to a lack of information about the specific practices, an issue also highlighted as a barrier to carbon farming uptake in Australia (Kragt, Dumbrell, and Blackmore 2017). There appears to be a clear opportunity to provide more information about the benefits of SCMP and particularly to emphasise their capacity to build resilience in the soil, an important characteristic in the light of future climate change challenges (Lal 2014).

At a national level, we have identified different stages of understanding about SCMP, pointing to development pathways to achieving carbon management. Some countries have provided some policy direction through regulation, such as the mandatory requirement to grow cover crops in Denmark. This has generated a growing interest in the issue, particularly amongst organic farms and large agri-businesses. In contrast, other countries such as Poland and Hungary are less advanced down the pathway to soil carbon management. We found that farmers' (and administration) awareness of environmental/climate threats is low. Current policy is primarily focused on meeting EU soil management obligations through cross compliance. The farmers in these countries need a clear policy signal that SCMP are demanded from them with accompanying advice programme that can tailor practices to individual circumstances.

The complexity and compatibility involved in implementing SCMP was also reported as a barrier to uptake. Farmers felt that they lacked the necessary skills and knowledge to implement the practices and integrate them into their existing management systems and regulatory requirements. Implementing these measures was demanding on farmer/adviser skills and knowledge since they were often unfamiliar and required a new skills set, more observation and monitoring and some understanding of soil processes. Participants in some regions (in particular Hungary, Poland, Spain and Italy) felt hampered by a lack of a regional advisory service to deliver these messages. Whilst advisers in most of the case study regions had a good knowledge of cross compliance soil protection requirements, their knowledge of managing soil for carbon tended to be low. There was a regional disparity in the level of existing knowledge. Both farmers and advisers in Denmark were better informed than in other study countries, reflecting access to a high standard of advisory service in this country. In Poland, advisers were generally unaware of the need for soil carbon management, or indeed more generally of the role of farming in climate change mitigation. This was attributed in part to poor adviser training. A clear opportunity exists for training advisers and extension workers in SCMP.

The ability to trial and to observe is particularly problematic for the adoption of new SCMP. Whilst it can be easy to trail and observe the impact of many agricultural innovations, such as the adoption of new crop varieties or technology, it can take up to 5 years before the benefits of SCMP are observed. This difficulty suggests that alternatives to the traditional knowledge transfer approaches are required to foster the uptake of SCMP. We identified a need with SCMP for the use of one-to-one advice, real life examples and farm demonstrations. Due to the uncertainties surrounding the benefits of SCMP farmers preferred to learn from other farmers, rather than depend on decision support tools. This preference supports the concept of farmers as social learners who are influenced by prestige bias (Moran, Lucas, and Barnes 2013). Farmers are more likely to copy those who have successfully implemented SCMP than rely on scientific knowledge or advice. Programmes should be developed that provide opportunities for farmers who have adopted SCMP over a number of years to share their experiences with other farmers with similar soils and production systems. This could be facilitated through the development of bottom-up farmer learning networks.

Moving towards innovation uptake

Our case studies have highlighted that even when the cost-effectiveness and abatement potential of SCMP are optimal, there are technological/agronomic, social-cultural, economic and institutional barriers that constrain uptake. Some of these barriers can be overcome through policy interventions, such as capital grants to purchase machinery. However, our research has highlighted that encouraging the adoption of SCMP is not simply just about fostering management practice change at the farm level, but also about providing the institutional and policy support for change. It requires new ways of, for example developing knowledge and skills, adapting practices to existing production systems, new markets and land tenure arrangements. These factors need to be taken into account when developing management recommendations and policy and advisory programmes.

Any future research on SCMP adoption needs to take a systems approach to the issue which integrates the different dimensions that can enable adoption: technological, socio-cultural and economic, and also explores the structural conditions of the agricultural innovation support system. SCMP are knowledge-intensive practices that need capacity building with farmers and advisory services. In fact, it may be more appropriate to talk about barriers and opportunities to achieving a series of practice change, rather than adoption (Ingram 2014), as land managers go through a learning process to understanding the longer terms benefits of SCMP.

6. Conclusions

The research has identified for the first time the range of technical/agronomic, economic, socio-cultural and institutional/policy barriers that impact the uptake of specific practices to increase soil carbon and which are assessed as cost effective (according to a MACC assessment)(McVittie et al. 2014). Furthermore, the research has identified regional variations in these barriers to, and opportunities for, the uptake of SCMP that would render any EU-wide level intervention ineffective.

Key regional barriers influencing the uptake of SCMP relate to existing biophysical conditions, lack of financial incentives, farmer knowledge and experience, and the quality of the advisory service. As the benefits of such practices are only realised in the longer-term, their relative advantages are not always apparent, nor is it easy to trial or observe the benefits of these knowledge-intensive practices in the short-term.

Three main opportunities emerged for increasing the uptake of SCMP. Firstly, the introduction of specific economic incentives to assist with, for example, the purchase or sharing of specialist machinery or to cover the transitional periods without benefits. Secondly, improvements in farmers' technical skills, particularly in relation to the more technically challenging practices, such as minimum tillage and cover crops. Finally, and importantly, the facilitation of networks for farmer-to-farmer learning opportunities to help farmers to identify and build their confidence in SCMPs that will work in their local area.

Reflecting further on the insights achieved in this research, the ultimate aim of introducing SCMP is to introduce carbon into the agricultural system to ensure the soil's long-term productivity and resilience. This requires a coherent policy and advice framework in which regulations and policy support are important for signalling and responding to societal expectations, but advice and engagement are equally important ingredients in helping to encourage sustained behavioural change on the ground. Ultimately, farmers need to recognise and understand the long-term benefits of SCMP and be encouraged and empowered to find long-term solutions. Given the dual benefits of increased soil carbon in restoring soil health and combatting climate change this might be a worthwhile investment for policy-makers.

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