Providing support in relation to the implementation of the EU Soil Thematic Strategy

Review of economic, social and environmental impacts of and implementation barriers for soil protection and sustainable management measures for arable land across the EU.

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Content

List of abbreviations

AEM	Agri-Environmental Measures
CAP	Common Agricultural Policy
CF	Cohesion Fund
EAFRD	European Agricultural Fund for Rural Development
EU	European Union
FAO	Food and Agricultural Organisation
GAEC	Good Agricultural and Ecological Conditions
GHG	Greenhouse Gas Emission
SDGs	Sustainable Development Goals
SOC	Soil organic carbon
SOM	Soil organic matter
SSM	Sustainable Soil Management

Executive Summary

Despite many efforts to promote more sustainable agricultural land use, e.g. through Rural Development Programmes including agri-environmental measures (AEM), Greening or Good Agricultural and Ecological Conditions (GAEC) standards, soil degradation of agricultural land in the EU is ongoing (see, for example, Baude et al., 2019; EEA, 2015; Panagos et al., 2015; Stolte et al., 2015). Agricultural management practices often are still unsustainable and are having a negative impact on soil functions and soil-based ecosystem services.

This report addresses the following questions: what are the reasons why measures to protect land and especially soils are not fully taken up by land managers? What are the barriers hindering the implementation of sustainable soil management (SSM) measures and the reasons behind them?

As a first step, the measures that are covered by the term "sustainable soil management" as listed in the FAO "Voluntary Guidelines for Sustainable Soil Management" are defined. These include measures for preventing, for example:

- soil erosion
- loss of soil organic matter (SOM) in minerals soils
- loss of SOM in organic soils
- soil compaction
- soil contamination
- decline in soil biodiversity
- soil acidification.

The empirical basis of the report is a literature analysis and a questionnaire sent to international research projects such as LANDMARK, RECARE, SoilCare, DIVERSFARMING, DIVERSIFOOD, AgriCO2ltura, Pegasus or ISOIL focusing on soil and land management asking for specific examples of implementation implications and barriers. Preliminary results were discussed at an expert workshop in March 2019 (for detail, see section 1.2).

Many SSM measures have already been addressed in different policies, only to a very different extent. The report shows that the application of SSM measures differs between different farming systems, such as conventional and organic farming. Even though SSM is not effectively implemented everywhere, the report outlines some examples of potential positive impacts. The list of economic, social and environmental impacts is long and has many facets.

The economic impacts can usually be pinned down to costs, whereas the environmental social impacts are more diverse and more difficult to identify and to frame. However, in this report examples are provided that highlight how to address and cluster the diversity of impacts. Moreover, besides the presentation of the list of financial, technical, social and cultural barriers to implement SSM, the report highlights several positive impacts of SSM on farmers and society and also ways to overcome the barriers.

Within the literature many examples of barriers are presented and the report is illustrated with specific examples from across Europe. Farmers – like other decision makers – are rather "attracted by short-term solutions and immediate benefits, while the full technical and economic benefits advantages of CA [Conservation Agriculture (note of the authors)] can be seen only in the medium- to long-term run" (Stagnari et al., 2010: 72).

Therefore, financial barriers are often quoted as critical factors for the implementation of sustainable practices (see, for example, Warren et al., 2016; Penov et al., 2011; Prager & Posthumus, 2010). They include a lack of investment capital, or periods without revenues and, at the same time increasing costs, for example, for labour.

Farmers' decisions about the choice of agricultural practices depend not only on profit but are also influenced by many other aspects, such as cultural beliefs, social norms, family, personal values towards nature or community. In addition, technical and administrative barriers, such as poor access to knowledge and support, can have a similar impact and hinder farmers integrating SSMs in their farming practise.

The report concludes with recommendations on how to overcome the barriers to SSM implementation. These solutions are not a one-size-fits-all approach and need to be selected on a case-specific basis. Recommendations include actions at different levels, for example:

Strategic policy framework

- Policy reforms towards supporting the implementation of SSM, including regulatory but also economic instruments in a policy mix.
- Reduction of incentives that lead to an increase in soil degradation, such as by energy policies that encourage cultivation of monocultures or the use of residues.
- Provisioning of governance structures that increase farmers´ access to information and advice.
- Stronger stakeholder participation in policy-making processes, including not only well-known lobby groups but a balanced representation of all relevant groups.
- Financial incentives at regional and national levels, such as tax reduction tailored to the SSM, mobilisation of additional funds (e.g. private) and collaboration activities between farmers.

Strengthening advisory services

- Awareness-raising campaigns and outreach activities to increase acceptance of sustainable farming actions (needs some policy support).
- Concepts for different farmer types, e.g. SSM experienced farmers, interested and not interested farmers.
- Ensuring independent and good quality advice

Increase research and development

- Research on new technologies but also on trade-offs between SSM measures is needed.
- Knowledge coproduction activities could be initiated and supported.

Ensuring financial support

- Advisory services and information campaigns require budgets.
- Existing funds can be tailored to support the implementation of SSM measures.
- Tax reductions and investment support can set incentives for farmers to take up measures.

1. Introduction

One of the main challenges for the future is to maintain soil functions, conserve biodiversity and ensure ecosystem services provision. Much literature already focuses on the challenge of land degradation and its impact on achieving, for example, the SDGs (IPBES, 2018; Keesstra et al., 2018; Tóth et al., 2018; Wunder et al., 2018; Orgiazzi et al., 2016). Despite many efforts to promote more sustainable agricultural land management in the EU, soil degradation on agricultural land in the EU is increasing (Stolte et al., 2015). Increasing soil degradation has already a severe impact on food production and the provision of ecosystem services. Agricultural policies became greener over the last few decades by implementing Rural Development Programmes, including AEM[1], in the second pillar of the Common Agricultural Policy (CAP) and by providing greening support to farmers to adopt farming practices that help to meet environment and climate goals under the first pillar. However, agricultural management practices are often still unsustainable and having an impact on soil ecosystem functions and services. In addition, there is still an information gap about the specific effects of policies on soil conservation in Europe.

Approaches to overcome the gap are, for example, systematic assessments of research projects, such as Pegasus[2] or LANDMARK[3], only to mention some, that analyse European policies and their specific measures in terms of their economic and ecological impact. They all come to almost the same conclusion which is that despite the fact that policies exist at European level, soil quality is neither sufficiently addressed by the member states, nor at the regional or local level: "Moreover, the embeddedness of soil stakes in policy packages at national and regional levels appears rather low in many countries and is still far from homogenous between countries" (Turpin et al., 2017: 247). So, EU policy instruments partly support the protection of Europe's soils, however, there is a lack of a strategic policy framework that links all policy instruments and, as such, increases the relevance of policy instruments to address soil degradation (Frelih-Larsen et al., 2017).

Farmers will adopt SSM if they regard the measures as helpful to achieve their environmental, economic and social goals. The implementation of SSM is linked with risks because the farmer is uncertain about the consequences and attached probabilities of this SSM. Figure 1 illustrates the high number of barriers, which range from policy timelines and bureaucracy to cultural issues. However, O´Sullivan et al. (2018) also show with this figure that incentives that could overcome the barriers exist. The incentives range from mandatory measures, which are, for example, addressed by e.g. the CAP or the EU Water Framework Directive to market and voluntary measures also addressed, for example, by the CAP through agri-environmental measures.

[1] Within the current CAP period agri-environmental measures (AEM) are called agri-environmental and climate measures (AECM). To avoid confusions in the report we use the term AEM which can also include AECM.

[2] http://pegasus.ieep.eu/

[3] http://landmark2020.eu/

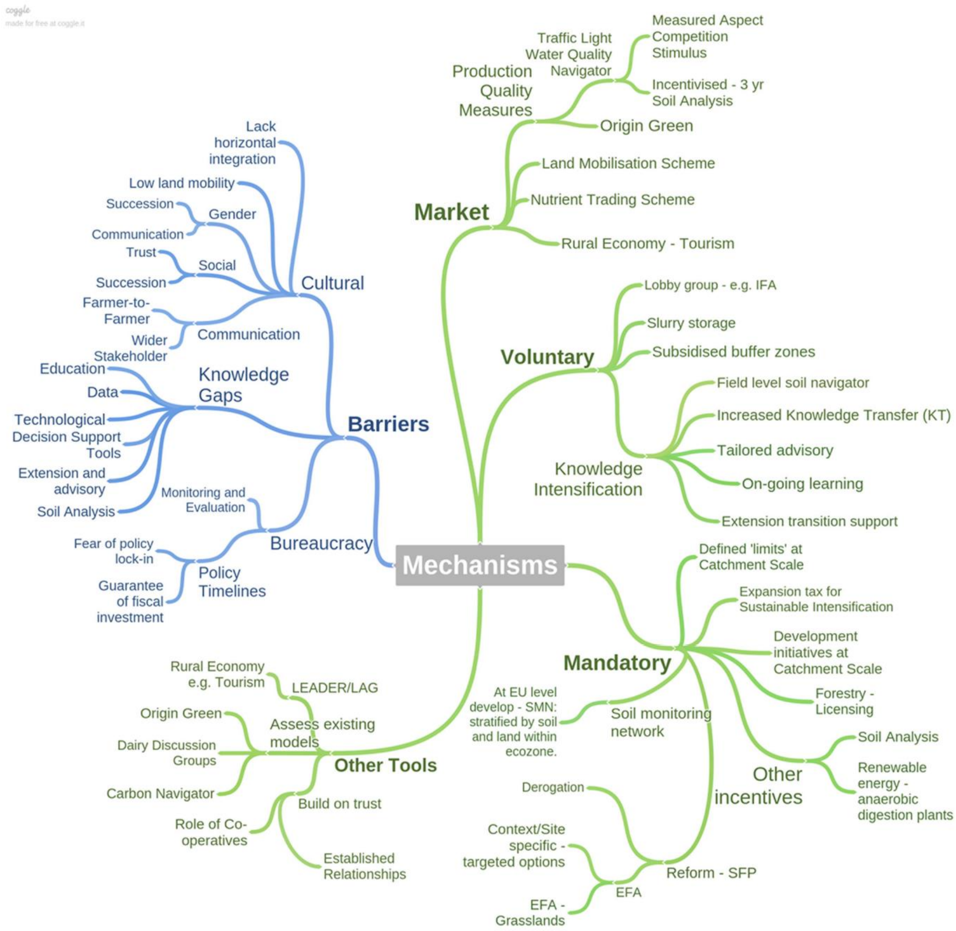

Figure 1: Gaps that inhibit optimised land and soil management, with the policy instruments required to steer change shown in green (O´Sullivan et al., 2018: 223).

1.1 Definition

The concept of sustainable soil management (SSM) is promoted to respond to increasing land degradation and aims at supporting land-based production and ecosystem functions (see, for example, Baritz et al., 2018). The FAO recently published the "Voluntary Guidelines for Sustainable Soil Management" (FAO, 2017). For the definition of "Sustainable Soil Management" the publication refers to the World Soil Charters' Principles according to which SSMs can be defined as sustainable "if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity. The balance between the supporting and provisioning services for plant production and the regulating services the soil provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern" (FAO, 2015: 4). The characteristics of SSM (according to FAO, 2017) are associated with following:

- Minimal rates of soil erosion by water and wind;
- Soil structure is not degraded (e.g. soil compaction) and provides a stable physical context for movement of air, water, and heat, as well as root growth;
- Sufficient surface cover (e.g. from growing plants, plant residues, etc.) is present to protect the soil;

- The store of soil organic matter is stable or increasing and ideally close to the optimal level for the local environment;
- Availability and flows of nutrients are appropriate to maintain or improve soil fertility and productivity, and to reduce their losses to the environment;
- Soil salinisation, sodification and alkalinisation are minimal;
- Water (e.g. from precipitation and supplementary water sources such as irrigation) is efficiently infiltrated and stored to meet the requirements of plants and ensure the drainage of any excess;
- Contaminants are below toxic levels, i.e. those which would cause harm to plants, above- and below ground fauna, humans and the environment;
- Soil biodiversity provides a full range of biological functions;
- The soil management systems for producing food, feed, fuel, timber, and fibre rely on optimised and safe use of inputs; and
- Soil sealing is minimised through responsible land use planning.

These characteristics focus on SSM for all land uses. However, in this report we will focus on agricultural land use only.

1.2 Structure of this report

What are the reasons why SSM measures are not always taken up by land managers? What are the barriers to implementing sustainable soil management measures and the reasons behind them? This report addresses these questions by defining the measures that are covered by the term sustainable soil management according to the FAO and how these measures are currently addressed at EU level. The report is based on a literature review, a survey among different research projects and results from an expert workshop. The literature review revealed that several national and international projects, such as LANDMARK or SoilCare, already address the question of barriers towards more sustainable land use in Europe. However, none of them focus specifically on SSMs, they are addressed, e.g. on barriers to implementing AEM measures or measures to mitigate impacts of climate change. Questionnaires were distributed among finished and ongoing international (research) projects that evaluate SSM measures and provide examples of impacts of and barriers to SSM. From seven projects answers were received.[4] The workshop was held on 29 March 2019 in Rome (called Soils4EU workshop in this report). 41 participants from 13 European countries attended the workshop. Participants were experts working in the field of sustainable soil management and represented all relevant sectors (representatives from different levels of public administrations and agencies (EU and EU Member States), land users (farmer's representatives and urban planners), farm advisors, environmental NGOs, International Organisations and academia).

The report addresses in the second chapter the sustainable soil management measures as presented in the Voluntary Guidelines of the FAO (2017). This is followed by a chapter on the positive as well as negative impacts of sustainable soil management measures. The fourth chapter discusses the barriers, which are manifold and range from purely administrative over technical and financial to socio-cultural. The report concludes with some recommendations that can serve as food for thought for future activities.

[4] LANDMARK, Diverfarming, SoilCare, Life – NEW LIFE, AgriCO2ltura, ISOIL, SolACE.

2. Sustainable soil management measures

2.1 Linking sustainable soil management to different farming systems

The report differentiates between farming concepts ranging from high-input to low-input systems without the intention to categorize them into "good" or "bad" farming systems. Sustainable management practices are also available for conventional farmers and their methods to prevent soil erosion, for example, can in many circumstances work faster than organic approaches (Tal, 2018). Farming systems have different histories, priorities and views on SSM, e.g. different opinions exist about the use and selection of fertilisers in conventional and organic farming systems. Moreover, in this report the examples show that it cannot be said that organic agriculture is taking up every SSM measure and conventional and intensive farming systems ignore all of the measures. In practise trade-offs exist between measures.

The high-input systems are characterised by a high intensity in production that could lead to higher yields but with the risk of more negative externalities for the environment, e.g. through the use of high amounts of fertilisers (Lin & Hülsbergen, 2017), which can impact human health, e.g. through polluted water. An example of a high-input farming system is conventional, intensive agriculture where high yields correlate with the use of fertilisers and pesticides as well as intense tillage. Low-input farming systems, such as regenerative agriculture (see 2.1.3) or organic agriculture (see 2.1.4) where the use of synthetic fertilisers and pesticides is prohibited, are usually characterised by lower yields (at least in the short run, not necessarily in the medium- and long-run) and a lower intensity in production but also by a smaller environmental impact. However the effects are context specific and have sometimes even adverse effects (Tal, 2018; Clark & Tilman 2017; Tuomisto et al., 2012).

2.1.1 Conventional agriculture

Conventional farming is an intensive and productive agriculture characterised by efficiency (Vasile et al., 2015). Conventional agriculture can be defined as "capital-intensive, large-scale, highly mechanized agriculture with monocultures of crops and extensive use of artificial fertilizers, herbicides and pesticides, with intensive animal husbandry" (Egri, 1999: 48). This farming system also requires the use of heavy machinery. The focus of conventional farming lies on the maximisation of production and profit (Fess & Benedito, 2018) with the consequence of environmental degradation and loss of ecosystem services (Vasile et al., 2015). Intensive agriculture capital is a substitute for land and partly also labour (Muller et al., 2017). The advantage of conventional farming is that through the use of fertilisers high crop yields can be realised (Brady et al., 2015). Besides the economic advantages, intensive farming methods may have a lot of ecological consequences such as biodiversity loss, contamination of soil and surface water, changes of landscape pattern (Markuszewska & Kubacka, 2017) and decline in soil fertility (Fess & Benedito, 2018). Therefore, SSM "is fundamental to effective soil function, particularly in intensive production systems where optimal plant growth is required to deliver maximal crop yield and quality." (Simmons et al., 2018: n.p.). Therefore, the level of conventional agriculture impact on the environment and soil degradation will depend on the farmers´ awareness of long-term consequences of a given soil management and the need to sustain soil capacity to produce high yield and high quality crops.

To reduce the ecological impacts of intensive production, and at the same time ensure farmers´ income, the CAP, especially Greening and Cross-compliance, promotes diverse SSM practices such as crop rotation, permanent grasslands, vegetation cover or the ban of ploughing within selected areas.

2.1.2 Conservation agriculture

Conservation agriculture is based on the three principles of i) minimum soil disturbance, ii) permanent soil cover and iii) diversified crop rotations and "offers a considerable environmental improvement of the agricultural ecosystems, without reducing yields" (González-Sánchez et al., 2015: XV). Herbicide treatments in conservation agriculture are on average higher than in plough-based systems (Lahmar, 2010), but González-Sánchez et al. (2015: XXVI) stress the fact that its application of plant protection products is safer than in conventional agriculture because "the risk of any off-site transport is much lower and the degradation rate of the products applied is enhanced due to a much higher soil microbial activity." Soil management based on conservation agriculture principles can increase SOM in agricultural soils as confirmed by (field) experiments in many European countries (Rieder et al., 2018; Borrelli et al., 2016; Laudicina et al., 2015). For the maintenance of permanent and semi-permanent soil cover mulching or intercropping shall be applied. With these farming techniques soils can be better protected against erosion or loss of organic matter and nutrient cycling and soil biodiversity are improved. Conservation agriculture can have positive effects not only on soils, but also on air (e.g. reduced CO_2 emissions into the atmosphere) and water (e.g. reduced runoff). (González-Sánchez et al., 2015). This farming system therefore addresses some of the SSM measures listed under 2.2.

2.1.3 Regenerative agriculture

Regenerative agriculture is a holistic land management type aimed at improving soil health, and carbon, nutrient and water cycling. It might refer to such practices as: no- or minimum-tillage[5], no bare soils, promoting plant diversity and the integration of livestock and cropping operations on the land. This farming system requires lower application of insecticides and fertilisers (LaCanne & Lundgren, 2018). It is a farming approach that enhances ecosystem services, while providing profitable nutrient-dense farm products. Regenerative agriculture has 29% lower grain production but it has 78% higher profits compared to traditional corn production systems (LaCanne & Lundgren, 2018). Examples of regenerative agriculture are agroforestry and agro-ecology.

Agroforestry is the integration of trees and shrubs on agricultural land. Tsonkova et al., 2018: 1091) point to the advantages of agroforestry systems: "Agroforestry systems are receiving increasing attention in temperate regions due to their capacity to counteract negative impacts of intensively managed systems." Examples of agroforestry systems are short-rotation coppice, orchard meadows or hedgerows (see Figure 3 for orchard meadows and hedgerows). About 20 million ha in Europe are covered with agroforestry (Hernández-Morcillo et al., 2018). Spain has the largest area of agroforestry with 5.6 million ha (den Herder et al., 2017). It can be classified in three types: livestock forestry (silvopastoral system), arable forestry (silvoarable system) and high value tree agroforestry (e.g. olive groves or walnut trees), (den Herder et al., 2017).

[5] In this report we refer to no-tillage when soil tillage is eliminated and to minimum-tillage when soil is tilled with implements which involve low mix of soil.

Agroforestry contributes to climate change mitigation and adaptation and can store more carbon than other farming systems. It supports nature and provides various environmental, economic and social benefits and ecosystem services such as nutrient cycling, pest regulation, reduction of soil erosion and flooding, increasing biodiversity. A study by Tsonkova et al. (2018) shows that positive socio-economic benefits of agroforestry systems are, for example, landscape aesthetics and tourism. Although agroforestry might contribute to SSM and has a lot of benefits for the environment and society, it is still not adopted on a large scale in Europe because of, for example, a lack of knowledge, limited support of experts and advisors and limited financial support from the CAP (Hernández-Morcillo et al., 2018). Moreover, although agroforestry allows the application of fertiliser, it has lower outputs than conventional intensive agriculture.

Agro-ecology focuses on food production with respect for ecosystem dynamics and natural cycles. A key component of agro-ecology is diversification of species and genetic resources through, for example, intercropping, mixed grazing and also agroforestry.[6] Soils and the related ecosystem services are preserved through land sharing (Muller et al., 2017), meaning that food production and the maintenance of biodiversity and ecosystem services happen at the same time on the same area (Fischer et al., 2014). This farming practice requires more land and labour but with less input of financial capital (Muller et al., 2017). The production aspect is important but negative impacts on the environment shall be minimised (Smith et al., 2017). An alternative form of sustainable intensification is ecological intensification (see, for example, Smith et al., 2017). The aim of ecological intensification is to augment crop yield by making use of ecological processes as substitutes for anthropogenic inputs such as synthetic fertilisers (see, for example, Bommarco et al., 2012). It includes regulating and supporting ecosystem services in agricultural farming management. This farming system acknowledges a wide range of SSM measures.

2.1.4 Organic agriculture

The share of organic agriculture within the member states differs widely between 23.4% in Austria and 0.4% in Malta and Iceland (EUROSTAT, 2019). Organic farming refers to the origin of agriculture - in the long human history family farms mostly applied organic practices (Tal, 2018). Organic farming is characterised by the ban of synthetic fertilisers and pesticides, while the use of genetically modified plants is strictly prohibited. Instead, organic fertilisers such as dung, nitrogen-fixing crops such as legumes (BMEL, 2018) and recycled nutrients are essential components of organic farming. In organic livestock farms animals have to be fed with organic fodder that is preferably produced in the same farm and have to be provided with enough space and an access to outdoor areas. It is based on natural control of pathogens and pests, crop rotation and the reliance on biodiversity to maintain soil fertility and sustainability and reduce the environmental impacts (Fess & Benedito, 2018).

[6] www.fao.org/3/i9037en/i9037en.pdf (File accessed 13/08/2019).

Table 1: Summary of prohibited and required practices in organic agriculture (Source: Meemken & Quaim, 2018).

	Crop production	Animal husbandry
Prohibited activities	• Use of synthetic fertilizers • Use of chemical pesticides • Use of genetically modified organisms (GMOs) • Use of sewage sludge	• Use of growth hormones • Prophylactic administration of antibiotics • Use of genetically modified organisms
Required activities	• Use of organic seeds and locally adapted varieties • Use of measures to improve soil fertility (e.g. crop rotation, organic fertilizer, erosion control) • Pest/ weed control only through mechanical/ biological/ thermic measures	• Animal housing that allows for natural behaviour (e.g. natural light, sufficient space) • Use of organic fodder • Access to pasture/ outdoor areas

Fess and Benedito (2018) conclude in their study that organic management practices are not per se sustainable. However, they also find that in the long-run these practices can contribute to system sustainability: "The limited use of artificial chemicals and the reduced reliance on production methods that require high energy requirements, in both the manufacturing and implementation, highly influence the sustainability of agricultural production." (Fess and Benedito 2018: 34). Organic farming supports a higher content of soil organic matter (Schrama et al., 2018; Tal, 2018; Seufert & Ramakutty, 2017) and higher soil fertility (Markuszewska & Kubacka, 2017). Moreover, through an improved soil structure, the risk of soil erosion can be reduced. Despite the potential ecological advantages, organic farming provides lower yields than intensive farming systems (Berentsen & van Asseldonk, 2016). The ban on the use of pesticides might require more tillage, such as ploughing. Organic resources can only slowly release plant-available nitrogen, making it unavailable during the crop growth period. Also, the amount of phosphorus can be low in organic farming systems (Meemken & Quaim, 2018), however, it depends on the farming system, e.g. when relying on animal manure (usually high in P) for fertilisation P can be quite high. Furthermore, organic agriculture is labour-intensive and requires specific production techniques. From the perspective of SSM measures organic agriculture incorporates many principles, even though intense tillage might be required because of the restriction on pesticide application.

2.1.5 High-tech industrial-engineering applied to agriculture

High-tech industrial engineering, such as vertical farming or algae protein bioreactors, are "rather delinking food production from natural ecosystem dynamics and soils. Such approaches aim at minimising impacts by maximal control of the processes and environments involved." (Muller et al., 2017: 102). For example, vertical farming avoids emissions, such as carbon dioxide and methan, despite of its use of artificial light and the fact that they have to be climate-controlled (Goldstein, 2018).

Moreover, the waste is supposed to turn into beneficial sources for instance liquid fertilizer or biofuel. (Kalantari et al., 2017: 85). Land and labour are also partly substituted by financial capital. Less soil is used and the tasks are rather that of an engineer (Muller et al., 2017). Some SSM measures, such as preventing soil contamination, are applied but others are not (preventing soil erosion) because soils are not used in a traditional way.

Precision farming is also listed under high-tech industrial-engineering and refers to a regionally differentiated and specific cultivation type of arable land. The aim of precision farming is the consideration of differences within a field. This has the advantage that the cultivation of soil and the application of fertiliser and pesticides are adapted precisely to the plant or desired object, so that the quality of the produced food can be increased and the cost of production and labour can be reduced. An example of technology used in precision farming is drones. They help to observe parts of the field that are difficult to reach. Drones can also recognise and combat weeds (Malveaux et al., 2014) and reduce soil compaction by minimising the use of heavy machinery. Other technological innovations are tractors controlled by GPS to cultivate or apply fertilisers more precisely on the field, so that costs can be reduced and production and profitability can be increased. Such approach will probably receive much more attention in the years to come due to the limited access to additional land for agricultural production, a growing world population and an increasing food demand. High-tech industrial-engineering farming systems apply many SSM principles, e.g. by supporting the prevention of soil contamination or soil erosion.

2.2 Sustainable soil management measures on agricultural land

This chapter lists and briefly describes the most recommended sustainable soil management measures for agricultural land as based on review by Bai et al. (2015) and selection by the authors of this report. They are presented in groups of measures that combat the most common soil degradation processes (see Table 2).

Table 2: List of most relevant sustainable soil management measures (SMM).

Category	SMM
Soil management	• Contour tillage • Minimum/no-tillage • Terracing • Ban of ploughing • Reducing traffic
Enhancing carbon input	• Vegetation cover • Mulching • Crop residue management • Application of exogenous organic matter
Optimizing production systems	• Permanent grasslands • Balanced fertilization • Conservation agriculture • Avoiding contaminants

2.2.1 Preventing soil erosion

Soil management

Vegetation cover – a dense plant cover reduces water erosion through reducing surface runoff and increasing infiltration. Plant root systems stabilise soil aggregates. Therefore, it is recommended to sustain vegetation cover for the entire year on the most susceptible sites. Planting grasses, shrubs and trees enables even the management of extremely disturbed areas and stabilises soil. Wind erosion is also effectively reduced by permanent vegetation. Selection of crops to be grown on erosion susceptible soils is a way to further limit degradation processes since plants differ in their capacity to reduce erosion.

Contour cropping and tillage – arable land susceptible to erosion shall be properly cropped and tilled. This measure involves tillage and growing crops along a contour line of the slope (rows or strips are perpendicular to the slope).

Minimum tillage and no-tillage – they reduce disturbance of the soil profile, protect soil structure, increase water infiltration, and reduce soil compaction, thus enhancing soil resistance to water and wind erosion.

Terracing – building mechanical structures (channels, stone walls, earthen ridges) can change the slope profile and reduce runoff and erosion. Terracing combined with permanent plant cover can be especially effective to reduce the risk of erosion in extremely susceptible sites.

Enhancing carbon inputs

Mulching – applications of plant residues cover the soil surface and protect against the impact of rain (see Figure 2). Mulching also promotes accumulation of water in soil. Leaving plant residues on the soil can also protect it from wind erosion. Artificial mulching materials are less recommended than organic materials, because they can cause plastic pollution.

Optimizing production systems

Planting shelterbelts or windbreaks – shelterbelts and windbreaks are planted perpendicularly to the prevailing wind directions and combat wind erosion especially in regions with high wind speeds.

Figure 2: Mulching on arable land (Copyright: Estación Experimental de Aula Dei, Zaragoza).

Figure 3: Windbreaks (Copyright: Estación Experimental de Aula Dei, Zaragoza).

2.2.2 Preventing loss of soil organic matter (SOM) in mineral soils

Soil management

Minimum tillage and no-tillage – besides limiting soil erosion these practices are recommended as potentially inducing SOM accumulation after a long-term period since in principle minimum tillage limits aeration of the soil and the related SOM mineralization. Furthermore, these practices increase soil biodiversity with the concomitant beneficial effect on SOM accumulation.

Enhancing carbon inputs

Crop residue management – it includes a range of measures, such as application of green manure, growing catch crops, perennial forage, cover crops and straw return that are incorporated into the soil. When properly managed (e.g. reducing tillage frequency and/or intensity), plant residues are slowly decomposed by the biota in soil and constitute a source of soil humus. Applying green manure enables sustaining or even accumulating organic matter in soil.

Legumes are especially valuable as green manure plants since they bring nitrogen to the soil, needed to decompose plant residues and to build permanent soil humus. A positive carbon balance in soil is key to ensure soil carbon preservation, e.g. through appropriate crop rotation. Cover crops are planted after the cash crops. They are a source of carbon, stimulate soil aggregation and protect against leaching of nutrients and erosion of soil particles. Soil erosion very often hampers the accumulation of soil carbon.

Application of exogenous organic matter – organic rich materials can constitute a significant source of soil carbon. Manure is a basic exogenous source of carbon; however in absence of manure materials such as compost, sludge, food waste or digestates might add carbon to the soil. Only uncontaminated organic materials can be applied to soil. The application of exogenous organic matter must be controlled and follow good practice recommendations to avoid excess of easily degradable organic matter and nitrogen that can cause environmental damage.

Optimizing production systems

Permanent grasslands are effective for soil carbon accumulation in mineral soils. Grasslands create conditions appropriate for soil carbon accumulation (higher moisture, limited aeration, constant plant residue input, and stimulation of microbial activity).

2.2.3 Preventing loss of SOM in organic soils

Soil management

Ban of ploughing – permanent grasslands on peat soils should not be ploughed to protect the soil carbon and water holding capacity of the soil. Ploughing organic grassland accelerates organic carbon decomposition processes.

Optimizing production systems

Conserving peatlands – in order to prevent a loss of carbon in organic soils, the natural conditions of organic soil systems must be maintained. Avoiding drainage of peatlands sustains organic matter accumulation processes. Drainage of organic soil initiates decomposition of SOM through oxidation processes. Peatland can be conserved by banning agricultural use, afforestation or by rewetting drained peatland.

2.2.4 Preventing soil compaction

Soil management

Tillage adapted to moisture conditions – it involves avoidance of tillage and traffic on field when soil moisture conditions are prone to produce compaction. For example, high soil moisture (i.e., after rain or snow melting.) results in higher risk for soil compaction when significant pressure (heavy traffic, animal grazing) is applied over soil surface.

Reduced traffic – Measures to reduce traffic may ameliorate compaction risk in soils susceptible to compaction. Practices such as controlling traffic (number of trips), reducing pressure on soil by decreasing axle load, lowering tyre pressure, adjustment of machinery and tillage to soil texture, are examples of measures aimed to decrease soil compaction through a reduction of traffic.

Enhancing carbon inputs

Measures increasing SOM in soil – Measures that promote accumulation of organic matter in soil also increase resistance of soil to compaction. Basically, soil organic matter enhances soil structure through the formation of stable soil aggregates. Better soil physical condition provides higher resistance to soil against processes which boost soil compaction.

2.2.5 Preventing soil contamination

Limiting contaminant inputs to soil –This measure includes controlled application of fertilisers, pesticides and waste residues and water which may be a source of pollutants. Also, control of the quality of the exogenous organic matter, waste water and fertilisers applied to soil.

2.2.6 Preventing decline in soil biodiversity

Enhancing carbon inputs

Maintaining SOM at appropriate level – input of organic matter as plant residues and from exogenous sources (e.g. compost) in general stimulate soil biodiversity through providing the energy source and improving conditions in soil.

Optimizing production systems

Conservation agriculture – Through its three pillars: minimal soil disturbance, permanent soil cover and diversification, it provides ideal conditions for soil biodiversity, since it provides a wide range of carbon and nutrient sources for soil biota and limits soil disturbance .

Controlling input of contaminants – application of safe exogenous organic matter and limited use of chemicals help to sustain soil biodiversity and representation or activity of various groups of soil organisms.

2.2.7 Preventing soil acidification and over fertilisation

Optimizing production systems

Application of liming materials – soil pH shall be monitored and liming materials (limestone, uncontaminated ashes) shall be systematically applied to soil in order to prevent natural and anthropogenic soil acidification processes.

Appropriate selection of fertilisers – fertilisers (especially nitrogen fertilisers) differ in their acidification potential. For example, ammonia sulphate acidifies soil more than fertilisers providing nitrogen in nitrate form.

Balanced use of organic materials and fertilisers – most chemical fertilisers induce soil acidification processes, whereas high amounts of exogenous organic matter stimulates acidification related organic matter decomposition. Fertilisation plans should be based on crop nutritional needs and adjusted to local soil and weather characteristics to not over fertilise soil and to avoid the risk of groundwater enrichment with nutrients.

2.2.8 Preventing soil salinisation

Enhancing carbon inputs

Crop residue management – Reduction of evaporation through the management of surface cover limits upward transport of water in soil profile preventing soil salinization.

Optimizing production systems

Appropriate irrigation – that involves testing and monitoring quality of irrigation water and ensuring sufficient water for plant growth and efficient drainage.

2.3 Integration of SSM into policies

Despite the importance of soils for human wellbeing and a healthy environment (Brevik and Sauer, 2015), there is not yet an overarching EU soil protection policy (Paleari, 2017). The **Thematic Strategy for Soil Protection** is still today the main framework with objectives for soil protection at EU level (Louwagie et al., 2011): 1) soil degradation processes shall be prevented and soil functions preserved and; 2) degraded soil shall be restored to a functional level. The Soil Thematic Strategy was launched in 2006 (COM(2006) 231) together with a proposal for a Soil Framework Directive (COM(2006) 232). This proposal was discussed unsuccessfully for eight years in the Council of the EU, before it was withdrawn by the Commission in 2014. Mainly two reasons let to member states to oppose the proposal which is concerns about subsidiarity and the potential high costs of the implementation of the Directive.[7]

At EU level various policies support SSM and cover water, air, industrial production, agriculture, urban planning, pesticide use, pollution and rural development. However, these EU policies and national initiatives often address soil functions only implicitly (Turpin et al., 2017). Member states have to adapt EU legislation to their own national legislation but they are flexible in how they implement these EU directives. The consequences are that the implementation of these directives can differ between the countries (Vrebos et al., 2017). In 2008, 410 different national soil conservation measures were counted in the member states of the EU. A few years later, 35 EU policies and 671 instruments deal with soils (Frelih-Larsen et al., 2017).

Frelih-Larsen et al. (2017: 177) argue in their 'Updated Inventory and Assessment of Soil Protection Policy Instruments in EU Member States' that "[g]iven the cross-sectoral nature of soil issues and the diversity of environmental and socio-economic pressures and governance conditions across Europe, it is not surprising that many different policy instruments at EU and Member State level exist that either explicitly reference soil threats or soil functions, or implicitly offer some form of protection for soils".

Monitoring and control are key challenges for the implementation of soil policies. Some policies lack the governance structures required for monitoring and enforcement as was identified for Brandenburg (Prager et al., 2011), where soil water erosion and compaction threaten arable land characterized by large farm and field sizes.

[7] https://ec.europa.eu/commission/presscorner/detail/en/IP_07_1988.

Also more local administrative staff involved in extension would be beneficial to raise farmers' awareness of soil degradation problems and for the success of policy implementations. Sometimes, policy objectives are not clearly stated, or are based on limited soil status data.

However, positive aspects and potential about the current legislation can be identified despite these shortcomings. For example, Frelih-Larsen et al. (2017: 11) found that "[t]he cross-policy analysis has shown a number of strengths relating to the coverage of soil threats and functions by existing EU laws".

At least the Environmental Action Programme puts pressure on member states to introduce appropriate measures, which protect soil stocks at EU level. These include "increase efforts to reduce soil erosion and increase soil organic matter; remediate contaminated sites and enhance the integration of land use aspects into coordinated decision-making involving all relevant levels of government; and support the adoption of targets on soil and on land as a resource." (Camarsa et al., 2014: 4). At member state level a total of 225 identified instruments (35.5%) are 'nationally initiated' policies, i.e. policies partly linked to EU non-binding policies or not linked to any EU requirements (Frelih-Larsen et al., 2017: 11). Few member states developed a comprehensive legislation for soil protection such as the Italian Legislative Decree No. 152 approving the Code of Environment (Part III (arts. 53-176) devoted to soil protection) and the German Federal Soil Protection Act (Federal Law Gazette I p. 502).

In terms of effectiveness, the flexibility of policies is relevant. The landscape, climatic conditions, soil types and other variables that are influencing farmers differ widely across Europe (Jones et al., 2012). Consequently, measures need to differ. CAP policy already provides scope for the national or regional design of measures to increase the effectiveness by tailoring it to the specific needs. With the effectiveness of measures, in particular agri-environment measures, also the potential for their acceptance and compliance will rise. For the design of Rural Development Programmes, in which agri-environmental measures are embedded, even regional stakeholders are involved (see, for example, European Network for Rural Development, 2015). The participation offers room for discussions about the applicability of measures to regional specificities and has the potential to increase the acceptance of farmers for the measures. However, not all soil relevant instruments do yet allow for regional specification and there is room to increase the regional specification of measures and integration of stakeholders.

3. Economic, social and environmental impacts of SSM

SSM measures have many impacts (economic, social and environmental) which can be either positive or negative. Table 3 provides an overview of these impacts which will be addressed in the following subsections. However, not all impacts can be illustrated with specific examples or case studies.

Table 3 List of economic, social and environmental impacts (based on literature study[8] and responses to questionnaire)

Environmental	Economic (to be considered at short-, medium- and long-term)	Social
• Water conservation (increasing soil water content, reducing water pollution, etc.) • Soil conservation (reduction of soil erosion, salinisation, acidification, contamination, sealing and compaction) • Biodiversity enhancement (promoting soil fauna, increasing, auxiliary fauna and beneficial insects, etc.) • Climate change mitigation (increasing soil carbon sequestration, reducing GHG emissions, etc.)	• Farm income and revenue (changes in yield, land value, subsidies, etc.) • Changes in production costs (on-site costs) (farm inputs, machinery, etc.) • Changes in off-site costs (reducing infrastructure investments, changes in food prices, new markets, etc.)	• Well-being of farmers (raising awareness, increasing leisure and family dedication, etc.) • Employment (changes in workforce, etc.) • Human health (increasing food safety, etc.) • Change in farm structure (risk of land abandonment, etc.) • Educational value (demonstration sites, school farms, applied learning, etc.)

3.1 Environmental impacts

There is still limited information about the actual effects of the implementation of policies and SSM measures on the effective conservation of soils in Europe. The Rural Development Programmes that require an ex-ante and ex-post evaluation and provide some information on the effectiveness of measures are an exception. The gap in information can inspire future programs and lines of research at European scale.

[8] Information about the cost-benefit analysis of maintaining soil functions in Europe is mainly limited to the study commissioned by the Directorate-General for the Environment on economic, environmental and social impacts of different measures to prevent soil degradation, in the context of the Impact Assessment of the Thematic Strategy on Soil Protection (SEC(2006)620).

3.1.1 Water conservation

An increase in soil water storage and an efficient water use is of vital importance for crop production. Soil formation can be considered as a supporting ecosystem service necessary for the production of many other provisioning, regulating and cultural services. Promoting soil formation increases the soil water content and then facilitates water conservation via the preservation of soil structure and porosity. Reducing soil erosion usually prevents crust formation and increases infiltration. The most widely reported benefit of conservation agriculture is the increase of soil water infiltration. Controlled traffic can improve soil structure, water storage in the soil profile and greater water use efficiency (Louwagie et al., 2009; Radford et al., 2007). Surface crop residues protect the soil surface from the impact of water drops reducing the susceptibility to soil sealing and crusting (Pareja-Sánchez et al., 2017), increasing water infiltration and reducing runoff and soil water evaporation. Cover crops improve soil N balance, reduce nitrate leaching losses (Plaza-Bonilla et al., 2015a), and avoid the eutrophication of inland and coastal waters (Aronsson et al., 2016).

The change from conventional to minimum tillage or no-tillage can improve water quality (Holland, 2004). There is evidence of runoff reduction by the adoption of minimum/no-tillage practices, which diminishes the load of pesticides, nutrients and sediments that can contaminate the soil and water. Cover crops increase the water-use efficiency of the cropping systems while reducing drainage of water with nitrates and pesticides. Effective nitrogen management (use of slow-release fertiliser, nitrification inhibitors, higher use efficiency, lower rates) also reduces losses of reactive nitrogen and preserve water quality. Crop diversity and crop rotation reduce erosion and water demand, and also nitrogen inputs. Crop conversion to natural and change from annual to perennial crop contributes to improve water quality.

Improved irrigation management reduces water quantity usage. Adequate irrigation planning has a direct influence on water use. Among others, volumetric water pricing of surface water and collaborative groundwater use are successful strategies to reduce water use in irrigated Mediterranean areas (Cortignani et al., 2018; Esteban & Albiac, 2012). Drainage also provides opportunities for conservation and water quality protection. The export of agricultural drainage water and associated pollutants to surface water can be managed and controlled using off-field practices (e.g. constructed wetlands, strategically located wetlands to reduce nonpoint source pollution). Controlled drainage can promote moisture storage in the soil profile and could reduce drainage volume and pollutant loads. Using vegetated open ditches is a management practice to mitigate potential agricultural contaminants.

Vegetation cover and above-ground biomass are the main factors affecting soil water storage and soil moisture conservation. Natural re-vegetation of fallow areas has been used to increase the stability of soil water storage. Buffer areas with riparian forests have been also used to increase the water-use efficiency and water quality, reducing also the impacts of extreme events in the soil. The use of vegetated wind barriers to reduce wind velocity decreases the evapotranspiration rate as it provides shades that conserve soil moisture. Wind speed over the soil surface is also reduced by crop residues, which act as wind-breaks over the soil surface decreasing evapotranspiration and soil temperature.

3.1.2 Soil conservation

There is a broad consensus on the positive effect of conservation agriculture practices in reducing soil erosion in Europe. The most widely reported benefits are the increase of soil water infiltration and the protective effect of crop residues on the soil surface. Soil salinisation and acidification have received less attention than other degradation processes in the member states' policies or policy implementation. The most severe salinisation cases occur in inland irrigated lands. Here, an adequate design and management of irrigation, including water application and quality, drainage, and adapted crops, will help to achieve desalination at the scale of a plot or in a whole irrigated district. The application of limestone to improve acidic soils has been practiced for centuries. However, the lime management practices at farm level can negatively impact the soil processes and functions due to nutrient unbalance and deficit and the loss of soil structure. Soil sealing is one of the main causes of soil degradation in the EU despite the guidelines and examples of best practices to limit, mitigate or compensate soil sealing in the EU-27 (EC, 2012) and the examples of existing member state policies and technical measures (Prokop et al., 2011). Some member states have established specific policies to reduce land take and sealing on their best agricultural soils and most valuable landscapes, although binding measures to prevent and limit soil sealing need to be established at the EU level. Sustainable soil management practices to limit soil compaction include systems to regulate the movement of livestock and cut down stocking densities, reduce tyre pressure and increase tyre size on large machinery within arable systems.

3.1.3 Biodiversity enhancement

Soil biodiversity plays a key role in regulating and providing ecosystem services. Soil microorganisms are responsible for soil nutrient cycles and, thereby, linked to soil fertilisation status. Moreover, soil fauna, such as earthworms and termites, contributes to the improvement of soil structure and porosity favouring water infiltration and reducing soil erosion processes. Soil management has a noteworthy impact on soil biodiversity. There are several examples of SSM measures that increase soil biodiversity. For example, the minimisation of soil disturbance (through the adoption of minimum and no-tillage techniques), the addition of organic inputs to soil (e.g., animal manure, organic amendments, compost) and the increase of crop diversity (e.g., crop rotations, cover crops) are some examples. Conservation agriculture, which encompasses the previous three aspects, has a significant potential to enhance biodiversity in European croplands. Experiments performed in different parts of Europe have reported a greater population of soil macro fauna, beetle diversity and abundance and arbuscular mycorrhizal fungi under conservation agriculture. For example, in Northern France, the combination of no-tillage and greater crop diversity (introducing cover crops) has an enhancing effect on soil biodiversity with increases in soil macrofauna, nematodes and microorganisms (González-Sánchez et al., 2017; Henneron et al. 2015). In the wettest conditions of Switzerland, the use of minimum tillage practices under organic agriculture had positive effects on the top-soil arbuscular mycorrhizal fungi with greater spore densities and species richness, when compared to conventional tillage (Säle et al., 2015). The diversification of cropping systems is key to improve biodiversity in European croplands. The diversification of crop species, with different roots structure and residue production and quality, favours soil microbial biodiversity and the presence of natural enemies of plant resistance to diseases. Biomass and abundance of earthworms were higher by a factor of 1.3 to 3.2 in the organic plots as compared with conventional plots (Mader et al., 2002).

The results of the Catch-C project long term experiments show that the application of manure and compost increase the abundance of earthworms (EC, 2015). Despite these evidences, there is still a limited integration of soil biology in policies and a general lack of awareness for the value of soil biodiversity, which in turn reflects the lack of basic knowledge about soil biota (Havlicek, 2012).

3.1.4 Climate change mitigation

Sustainable soil management measures can mitigate climate change by (i) sequesting soil carbon and (ii) reducing the emission of greenhouse gases. Soil organic carbon sequestration is the result of increased soil C inputs and/or reduced C losses.

Emissions of greenhouse gases CO_2 and N_2O from no-tillage soils are highly variable and depend on complex interactions of soil properties. For this reason, there is an unresolved controversy about the practices with ability to fixe or not carbon in the whole profile of the soil. Increased soil organic carbon in surface layers of no-tillage soils may not be associated with increased carbon sequestration throughout the profile (Soane et al., 2012). However, there is a wide corpus of literature on the different management measures that can increase soil C inputs. Among them, the introduction of cover crops and perennial crops into cropping systems, the maintenance of crop residues, the use of no-tillage, and the use of organic amendments, such as compost or farmyard manure (e.g. Poeplau & Don, 2015; Virto et al., 2012). Under certain conditions soil carbon losses are mitigated when using reduced and no-tillage as a result of greater C inputs and/or decreases on microbial decomposition, and by the application of measures to mitigate soil erosion. In organic soils soil organic carbon is preserved and CO_2 emission is mitigated when avoiding peatland-drainage. Data from long-term field experiments and modelling are the most commonly used approaches to estimate the carbon sequestration potential of agricultural soils. For instance, in a simulation study, Borrelli et al. (2016) found that the application of GAEC (Good Agricultural and Environmental Conditions) to the total arable land in Italy resulted in overall SOC gains, modulated by the agroecosystem characteristics. Other simulations have shown the potential of conversion of European agricultural soils into grassland as a major SOC sequestration measure with values between 0.4 and 0.8 t C ha^{-1} yr^{-1} (Lugato et al., 2015).

Greenhouse gas emissions from agroecosystems, such as nitrous oxide (N_2O), are usually a consequence of a lack of synchronisation between crop needs and soil nutrient availability. An adequate management of synthetic fertilisers avoiding nitrogen (N) surpluses leads to the reduction of N_2O and other losses, like nitrate leaching, as regulated by the Nitrates Directive (EC, 1991). Therefore, sustainable soil management practices promote nutrient recycling and an adequate external nutrient supply according to crop needs. The introduction of legumes in crop rotations, as requested by Greening, improves soil N balance through symbiotic N_2 fixation with soil bacteria and reduces the emission of greenhouse gases (Plaza-Bonilla et al., 2017; Peyrard et al., 2016). Likewise, adequate water management in lowland rice cultivation reduces soil organic matter anaerobic decomposition and CH_4 emission to the atmosphere. Despite total rice-growing area within the 27 Member States is only about 450,000 ha, the average annual production is about 3.1 million t of paddy rice being EU self-sufficiency in rice about 70%.

Perennial bioenergy crops show a clear advantage in mitigating GHG emissions (Hillier et al., 2009). These crops show higher sequestration of carbon than under arable conditions (Gregory et al., 2018; Agostini et al., 2015). Moreover, the impacts of perennials on food production are very small when done with measure and targeting less fertile soils (Karp & Richter, 2011; Lovett et al., 2009).

3.2 Economic impacts

Sustainable soil management practices can produce private profits for farmers, through improvement of soil fertility and structure and soil and water conservation, among other benefits. Although differences exist between humid and dry areas, these benefits can lead to the increase and stability of agricultural production systems, which, in turn, can enhance agricultural returns and food security (Branca et al., 2013).

A fundamental idea of the Global Initiative on the Economics of Land Degradation (ELD) is that the economic benefits of actions aiming to prevent or reverse land degradation are higher than the costs of those actions. Here, land degradation has a broad meaning including on-site and off-site effects, and the costs include social issues. Probably this idea focusses on large scale and long-term land restauration projects, which can provide economic rates of return of 5%-50%. The benefits can exceed the cost at least two times over a 30-year planning horizon globally, as is the case of land restauration programs in Uzbekistan (Nkonya et al., 2016). Literature on case studies is probably conditioned by specific local contexts of the different countries, which are highly and sufficiently heterogeneous in terms of biophysical, socio-economic and institutional characteristics.

3.2.1 Farm revenue and production costs (on-site effects)

Estimating the economic impact of SSM measures in monetary terms is complex and estimates are heterogeneous and sometimes imprecise. There are links to indirect information, as well as assumptions and uncertainties, especially for soil conservation measures applied independently of the government incentives or EU funds. Regarding only what is currently supported by governments and co-funded under CAP agri-environmental measures, the estimated EU costs allocated to soil conservation measures are 1292 million € per year (Kuhlman et al., 2010). The total monetised benefits (on-site and off-site) of the measures aiming at reducing soil erosion on agricultural land are smaller than the total costs, especially on-site costs. However, a positive balance occurs when the different soil measures are considered together, e.g., measures for erosion and organic matter on the whole. The quantifiable costs and benefits of applying eight measures and 15 different practices for sustainable soil management in the EU are summarised in Table 3.

Some studies have shown that the savings of implementing certain soil conservation practices do not fully compensate farmer revenues. For example, despite the obvious effects of straw mulch on reducing erosion by 128 times after a decade of practice, farmers mainly retain that straw mulch is more expensive than the traditional tillage (straw mulch costs 394 € ha^{-1} while traditional tillage costs 204 € ha^{-1}) (Cerdà et al., 2017). However, several studies have revealed that the adoption of measures listed as SSM reduces costs and increases farmer's revenue. For example, in Southern Spain, no-tillage practices compared to conventional tillage may reduce costs by 59.6, 72.7 and 62.0 € ha^{-1} on wheat, sunflower and leguminous, respectively; and the spontaneous groundcover may reduce olive costs by 18 € ha^{-1} compared to conventional tillage (González-Sánchez et al., 2017).

Table 4: Overview of quantifiable costs and benefits (Source: Slightly adapted from Kuhlman et al., 2010: 30).

Measure	Practices	Threat at which it is aimed	Cost p.a./ha (€)	Risk area (m ha)	Total cost p.a. (m €)	Current expenditure p.a.	Addit. costs of prop. policy (m €)	One-site benefits p.a. (m €)	Off-site benefits p.a. (m €)	Balance: net benefit (m €)
1. Serious erosion (>10 t ha^{-1} yr^{-1})	Conversion of arable land into forest/pasture, terracing (construction, maintenance), buffer strips, residue management, cover crop, conservation tillage	Erosion, SOM loss, compaction	296	8.1	2398	1292[a]	11578	3250	1800	–1354
2. Moderate to serious erosion (2–10 t ha^{-1} yr^{-1})	Buffer strips, residue management, cover crop, conservation tillage	Erosion, SOM loss, compaction	140	22.7	3178					
3. Moderate erosion (0.5–2 t ha^{-1} yr^{-1})	Linear elements, contour ploughing, residue management, cover crop, conservation tillage	Erosion, SOM loss, compaction	120	31.3	3756					
4. Level areas, SOM loss only	Residue management, cover crop, conservation tillage, application of EOM	SOM loss, compaction	116	30.5	3538			2057	3117	
5. Specific anti-compaction measures	Low-pressure tyres	Compaction	4.5	40.4	182	60	122	1072	–	905
6. Level areas, salinization	Drip irrigation	Salinization	1076	7.15	7688	384	7304	2887	606	–3811
7. Soil protection in forests	Reduced-impact logging	Erosion, SOM loss, compaction	450[b]	1.2	547	109	438	18.2	280	140
8. Soil protection on construction sites	Safe stormwater disposal, sediment trapping, seeding, stabilized entrance	Erosion	22159	0.011	246	0	246	0	60	–186

Although the restoration costs of salt-induced soils are high (e.g., $810 million in the Ebro River Delta, Spain), the restoration of saline soils has increased the productivity and farmers income, as reported for Hungarian steppes and Kazakhstan (Qadir et al., 2014).

Similarly, controlling soil erosion helps to increase yields and thus economic income to farmers. For example, minimum tillage, furrow pressing, spreading manure on topsoil and adjusting the crop rotation, can increase the protection against wind erosion reducing the cost of damage from 61 to 36 € per ha (Ricksen & Graaff, 2001). In Sweden, 20% of the farmers apply measures to control the soil erodibility and wind erosivity, being furrow pressing the only measure that is used by all farmers (Rickson et al., 2015). However, since these measures increase the cost (water and chemicals use, and labour) and reduce yield and benefits, they are applied depending on the contribution of a crop to the farmer´s income.

3.2.2. Off-farm costs and benefits

Off-farm costs of soil protection measures could be higher than the associated costs on farm. As an example in France, the on-site cost associated to soil erosion was 36 € ha^{-1} yr^{-1}, the off-site cost associated to the implementation of soil conservation measures (implementation and maintenance costs), remediation measures (e.g., removal of sediments on roads) and government subsidies were 49 € ha^{-1} yr^{-1} (Darmendrail et al., 2004).

Many soil protection measures have an economic impact off-farm, e.g. under certain circumstances, the adoption of sustainable soil management practices may impact food prices. For example, the use of green manures in ecological orchard production in Murcia region (Spain) increased biodiversity and reduced the use of chemical pesticides. Meemken & Quaim (2018) found in a literature study that the output prices would rise in case of widespread upscaled organic agriculture. For the reduction of pesticide use, the monetary benefits are most likely accessible. However, monetary benefits of biodiversity conservation do not exist in many cases. Therefore, cost benefit analyses usually do not exist and only the costs (e.g., higher food prices) are presented and the benefits are underrepresented.

Soil erosion by water reduces crop productivity by 0.43% per year and produces economic losses in terms of gross domestic product. Based on biophysical together with macroeconomic models, Panagos et al. (2018) estimated the annual cost of agricultural productivity loss due to soil erosion in the European Union at around €1.25 billion, being Italy, Slovenia, Spain and Greece the most affected countries. These costs need to be compared with the costs and benefits of SSM measures. Such studies are still missing but are urgently needed to understand the impacts but also trade-offs of measures. Solid data will allow programmes to further support the implementation of SSM measures.

3.3 Social impacts

Despite its importance, there are very few studies in the European Union focused on the social impacts associated with the implementation of sustainable soil and/or land management measures. Economic considerations (e.g., production, farm income increase, well-being and livelihood improvement and reduced workload and costs) are land users´ and farmers' primary motivations for adopting sustainable management systems (Giger et al., 2018). For instance, the economic benefits that can result from the adoption of conservation agriculture practices (e.g., reduction in labour requirement and associated costs, and reduction of fuel and machinery operating costs and maintenance) can improve the well-being of farmers and people living in rural areas, but the available information on this particular issue is still very scarce. However, the adoption of sustainable management practices not only depends on economic benefits but also on other non-economic benefits such as personal satisfaction and/or pleasure. For example, organic farmers report higher levels of subjective well-being or life satisfaction, compared with conventional ones (Mzoughi, 2014).

Concerning the impact of sustainable management systems on employment opportunities, the information is basically available for measures applied in organic farming systems. Conversion from conventional to organic agriculture implies new job opportunities in on-farm processes (e.g. special handling and quality sorting), non-farm production of organic inputs in agriculture (e.g. natural fertiliser) as well as jobs in post-harvest farm-to-market supply chains (Herren et al., 2011).

Organic farmers often have a critical view on the negative effects of pesticides on **human health** and food quality. Koesling et al. (2008), for example, refer to other studies that point out to family health as one determinant factor for conversion to organic farming. Organic farmers consider that their products are healthier for consumers than conventional products, most of which rely on the use of pesticides. In this respect, it is worth mentioning the herbicide glyphosate, the most sprayed pesticide in the world, and the current social concern about its potential negative effects on the environment and on human health, a social and scientific issue, are still very unclear and controversial (Torretta et al., 2018).

Agroforestry - land use systems and practices in which woody perennials are integrated with agricultural crops and/or animals on the same land management unit - has different social impacts. When correctly managed, agroforestry systems (for instance, the so-called “dehesas“ in Spain and “montados” in Portugal, which consist of combining oak trees with animal grazing or cereal crops) can be very beneficial for land users and their environments, as they improve the aesthetic value of the landscape, food and water security and livelihood and well-being, among other impacts (Marques et al., 2016). In addition, forests and trees, which are able to fix air pollutants, contribute to provide cleaner air for people.

4. Barriers to the implementation of sustainable soil management measures

Farmers' decisions, including the decision to implement SSM measures, are driven by a **variety of** factors that are often interlinked. Economic rationality, associated risks of actions, required effort, cultural background, educational level, trust between stakeholders or other social factors which are often very important in farmers' decision making.

Table 5 shows that the list of factors influencing the decision making of a farmer is long. A farmer will consider all factors in his farming system and will only change to a different farming practice, e.g. SSM, if that system will be advantageous for him/her. However, all these factors can constitute a barrier for the farmer to make changes to his/her farming system.

A number of examples of barriers to implementing measures listed under SSM are mentioned in the literature. For this report, we clustered them into financial, technical, administrative and cultural/social barriers. Some barriers mentioned, such as "Lack of equipment and investment capital" and "Investment uncertainties" overlap because most barriers are to some extent interlinked. However, for the purpose of readability and clarity, the aspects are presented individually. At the end of each sub-chapter solutions to overcome these barriers are presented and discussed.

Table 5: Most relevant barriers to the implementation for SSM by farmers (Source: Based on Cornell et al., 2016; EC, 2015; ELD Initiative, 2015; responses from questionnaires and Soils4EU workshop)[9].

Financial	Technical	Administrative	Politics	Cultural/Social
• Investment uncertainties (e.g. when changing farming systems) • Lack of equipment and investment capital • Additional costs (e.g. for labour or new machinery)	• Lack of knowledge (e.g. how to use the equipment and implement measures)	• Lack of support (e.g. in form of advice from administration) • High transaction costs (e.g. for the implementation of measures in terms of field monitoring) • Measure design conflicting with SSM	• Other policies conflicting with SSM	• Mental models of society and other farmers (→ prohibiting changes in farming practices) • Demographic factors (e.g. different interests between old and new generations, farm succession) • Self-image and life satisfaction of farmers

4.1 Financial barriers

Financial barriers are mentioned in many studies as a relevant (even though often not the only one) factor that hinders the uptake of sustainable management measures such as soil protection measures (see, for example, reviews by Bartkowski & Bartke, 2018; Prager & Posthumus, 2010). In one of the surveys on barriers to the implementation, more than half of the farmers identified financial incentives as the most important (Penov et al., 2011).

9 The table does not fully correspond with Figure 1 because for the report we chose the most relevant aspects as mentioned in the literature.

Recent reviews of empirical studies on farmers' adoption of Best Management Practices (Liu et al., 2018) and of farmers' soil-related behaviour (Bartkowski & Bartke, 2018) similarly demonstrate the importance of economic factors for the willingness of farmers to take up sustainable soil management measures. Farmers are, for example, concerned about the transition costs typically required to implement SSM measures, the lack of equipment and investment capital as well as additional costs, such as for labour. Farmers are businessmen and -women and therefore need to calculate costs and benefits as part of their farm management: "Indeed, investing in a new and powerful tractor involves long-term technical and economic constraints" (Vuillot et al. 2016: n.p.). Moreover, farmers are rather short-term oriented as Stagnari et al. (2010: 72) point out: "[F]armers are always attracted by short-term solutions and immediate benefits, while the full technical and economic advantages of CA can be seen only in the medium- to long-term run". The competition in the world market of agricultural products is high and climate change, with such extreme weather events as those experienced in summer 2018, put additional pressure on farmers.

4.1.1 Investment uncertainties

A crucial challenge is that **short-term investments are needed which usually pay off in the long-term**. This can result in periods with negative or without income. In the short-term the conversion of the farming system can imply financial losses for the transition period, however many farmers across Europe are well educated and aware that soil degradation will endanger yields and farmer's profitability and productivity in the long-run. Investing in equipment requires **clear prospects for profitability** (here is an important link to the institutional framework, including adequate land tenure). Especially due to climate change conditions for cultivation, care and harvest conditions are often not foreseeable (see, for example, the dry summer 2018).[10]

The Catch-C[11] project analysed drivers and barriers for farmers to adopt 'best management practices' which are close to the SSM measures, such as crop rotation, use of organic manure, minimum or no-tillage and incorporation of crop residues. As barriers to non inversion tillage, besides others, the fear of yield loss, weed pressure and the need for specific equipment were mentioned, but also legislative restrictions (Bijttebier et al., 2015). However, the barriers and their impacts differ between the case study countries they analysed (Bijttebier et al., 2015).[12]

4.1.2 Lack of equipment and investment capital

For no-tillage problems may arise which are linked to, for example, straw and stubble management, incidence of weeds or diseases (Lahmar, 2010). Specific sowing equipment and herbicide sprayers are key requirements for the implementation of SSM. In fact, the smallholdings frequently found in Italy, Poland and Spain may not be in a financial position to invest in new machinery (Ingram and Mills, 2014). Moreover, in specific cases, the technology required in a specific location may not be available, accessible or compatible with current farming operations.

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[10] During extreme weather events economic considerations urge farmers not to apply optimal crop rotations and measures to take care for soil.

[11] http://www.catch-c.eu/

[12] See Pronk et al. (2015) for a list of drivers and barriers identified by the Catch-C project.

The implementation in Europe of conservation agriculture that requires SSM is an interesting case study for financial barriers. While conservation agriculture was introduced by the need to reduce crop establishment costs, CA is in Europe seen sceptical in terms of its suitability for the climatic condition and cropping system, but also the high cost of the equipment and the ”hands-on management needed” (Stagnari et al., 2010: 72).

Especially for small farms, **high investments in innovative technology** such as for tillage are **often not reasonable** because they do not have economies of scale, like larger farms do. Moreover, new technologies such as innovative sowing machines are sometimes too large for small fields, so using them is not feasible from a technical perspective.

4.1.3 Additional costs

Additional costs may be related to additional inputs, such as labour or agrochemicals. The reduction of the application of synthetic fertilisers and pesticides to reach a sustainable and environmentally friendly agriculture could **require intensity labour,** e.g. for additional tillage or even manual work for weed control. In some cases, additional labour required for the implementation of soil management techniques may not be available. The current decline in family farming and rural population poses additional threats to labour force availability. Referring to an EU study, Tal (2018: 11) states that “the average size of the labour force of fully organic farms farm was 1.5 annual work units while non-organic farms were only 0.9.“ On highly productive land the application of certain measures might lead to a loss in revenue. In such a case, even financial support for agri-environmental measures is not attractive to famers because it leads to financial losses at least in a short-term perspective. However, an increase of the effectiveness of agri-environmental measures is needed to support environmental impact reduction of agriculture (Früh-Müller, 2019).

4.1.4 Solutions

Overcoming financial barriers is extremely relevant because it influences the decision-making of farmers, especially risk-adverse ones. **Incentives** and **subsidies** have often been requested by farmers to facilitate the introduction of management measures with positive externalities for society at large. For example, subsidies are seen as important in motivating conventional farmers to switch to organic practices (Meemken & Quaim, 2018). The CAP already provides financial incentives, for example, through the Rural Development Programmes, but as mentioned above, these measures, such as AEM, are not always attractive enough. Other support is provided for farmers changing their farming practise to organic farming. Likewise, **young farmers** can apply for **financial support**, e.g. to invest in new innovative technologies: “Young farmers are encouraged by additional support from the CAP's direct payments: national authorities have to set aside up to 2% of their total allocation of direct payment funding in order to offer young farmers a bonus of 25% (maximum) on their direct payments in their first five years of working in the sector. Young farmers also have priority when it comes to receiving direct payment funding from the national/regional reserve”[13].

[13] https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/income-support/young-farmers

Besides public financial support, **cooperation between farmers** can also decrease the financial barriers. This cooperation can be for production, or marketing activities, or both: To **lower the financial risks of new investments**, farmers can cooperate and share machinery. Approaches range between borrowing machinery from neighbours or the machinery ring to being a partner in a **partnership under civil law** that owns the machinery. Berti & Mulligan (2016) elaborate on the idea of Food Hubs that allow small farms to stay competitive in the existing agri-food system and at the same time follow the path of sustainable production. Key attributes of the Food Hubs are "Quality, safety and healthiness", "Sustainability and healthiness" and "Locality". It is only one out of many examples that show how cooperation between farms supports risk reduction of a change in management practice.

During the Soils4EU workshop the issue of external funding was raised: Water companies in the UK, such as the Cambridge water company[14] or Wessex Water[15], have own advisors and offer financial support/extension for farmers to ensure water protection through sustainable land management. Bayer follows a similar approach and financially supports kind of show farms that represent a typical farm for a specific region and applies sustainable agricultural practices[16]. In cooperation with WWF Coca Cola provides funds to farmers for applying voluntary measures to improve the river water quality in English rivers.[17] In the workshop discussion it was said that the approach is effective and that Coca Cola does not try to influence the project design and implementation too much. WWF is rather responsible for the projects.

Insurances for farmers exist for a wide range of themes such as crop yield insurance, fire or storm insurance. Insurance providers could develop insurance solutions that capture the inherent risk of farmers who are changing their farming system.

4.2 Technical barriers

In this subsection we apply a wide understanding of technical barriers from physical and technical to soft skills. Technical barriers to the implementation of soil protection and sustainable management measures has two crucial elements: farmers first need to gain access to the technical knowledge and then they need the equipment required for an effective implementation. Hence, first farmers **need to know about new techniques**, how these function and if they improve the farming system and afterwards the question of access to capital needs to be solved.

4.2.1 Fit of (new) technologies

Not all SSM measures fit to all soil or climatic conditions in the same way. The EU funded project SmartSOIL[18] identified several technical and agronomic barriers related to climatic and environmental conditions that can have an impact on the uptake of soil carbon management practices (Ingram & Mill, 2014): For instance, cold weather conditions can hinder the establishment of catch crops.

[14] www.cambridge-water.co.uk/environment/biodiversity-and-catchment-management/entrade

[15] wwtonline.co.uk/news/new-entrade-scheme-helps-farmers-protect-poole-harbour

[16] www.cropscience.bayer.com/en/crop-science/forwardfarming

[17] www.wwf.org.uk/what-we-do/projects/working-coca-cola-improve-english-rivers

[18] http://projects.au.dk/smartsoil/

Similarly, in Scotland, cover crops are difficult to establish due to late harvest and weather-related constraints. On the other hand, dry weather conditions can also affect crop sowing and growth. Thus, while in Mazovia, Poland, the sowing of catch crops can be impacted by autumn drought, legumes, in arid conditions in Andalucía, Spain, do not grow well.

Soil type and properties can also influence which soil management practices are implemented in a region. For example, sandy soils of the Central Region in Hungary are not suitable for cultivating legumes (Ingram & Mills, 2014). In Scotland, minimum tillage does not work well due to inappropriate soil conditions (Ingram & Mills, 2014). Likewise, soils with weak structure and limited drainage in the UK are not suitable for no-tillage since crop yields tend to be lower than under ploughing (Soane et al., 2012). In Denmark and The Netherlands, no-tillage implementation is also constrained in sandy soils with weak structure (Soane et al., 2012).

No tillage and/or the use of alternative crops in rotations are also constrained in areas where primary production potential is low. Under the condition of limited rainfall, crop residue production in rainfed agriculture compared to irrigation agriculture is reduced (Plaza-Bonilla et al., 2015b), and thus could negatively influence the success of minimum tillage and no-tillage techniques in terms of soil erosion mitigation and soil carbon storage. In a crop rotation study in European Mediterranean conditions, the adoption of alternative crops to the typical wheat and barley mono-cropping failed in 80% and 35% of the growing seasons in the case of rapeseed and vetch, respectively (Álvaro-Fuentes et al., 2009). Authors attributed the poor performance of these alternative crops to the low soil water content for crop growth.

4.2.2 Lack of knowledge

SSM measures are usually knowledge-intensive. Multiple empirical studies have stressed the importance of knowledge and support (e.g. by advisory services) for the adoption of such measures (Bartkowski & Bartke, 2018). In Spain, for instance, Marques et al. (2016) reported a noticeable **lack of specialised training and awareness**. This is a relevant limitation since farmers need to be familiar with the technical measures and they need to see them applied in the local cooperative or in an experimental station (Penov et al., 2011).

A well-known example of knowledge intense farming is organic farming. It can be more intensive in knowledge than conventional farming. Farming organically requires more time to acquire knowledge about innovation, experiments and exchange of knowledge. Organic farmers need to learn more about ecosystem and the adaption of cultivation methods on local conditions (Jansen, 2000).

While some farmers have good knowledge about the impact of different management practices on the environment from practical training, other farmers gain their knowledge from long-term experiences or experiences neighbouring farmers made. Even though many farmers are highly qualified and familiar with regulations, these change quite frequently and require access to information. However, access to reliable information is not always straightforward. Whereas in the Netherlands advisory services are fully privatised, in some federal states in Germany to get advice, farmers either have to pay or contact a unit at the regional authority. However, the unit giving advice for some questions is at the same time the unit that is responsible for the on-farm inspections, which is a serious barrier for some farmers although a strict separation is claimed.

Even if farmers get access to some knowledge sources it does not ensure they receive the information they need because there is still a **lack of reliable, available and relevant information** (Rodriguez et al., 2008; Egri, 1999). Lack of knowledge also still exists in science as Simmons et al. (2018: n.p.) point out: "[l]ittle is known of how practices such as tillage/cultivations or the use of organic amendments and crop residues affect the persistence and transmission of crop biotic threats. This lack of knowledge is hindering our ability to generate sound evidence of how soil management determines both crop health and productivity. Guidance needs to be developed on how to manipulate soil properties that will enhance the ability of soil to suppress crop diseases and pests through sustainable soil management."

The development of new knowledge has traditionally been in the hands of public and private research and development institutions. The transfer of the information to farmers then requires scale considerations, as well as tailoring and targeting (Liu et al., 2018). However, Schneider et al. (2009) found in their study that for the aim of more sustainable agriculture, the co-production of knowledge between farmers, experts and scientists is crucial. It would also break up the discrimination between scientists and experts on one side and farmers on the other and improve the knowledge transfer.

4.2.3 Solution

Not all farmers are aware of the benefits of the measures or available techniques and skills relevant for SSM. Studies investigated that academic education has a lower value for farmers than the skills and knowledge gained through day-to-day experience often from childhood on when growing up on a farm (see, for example, Sutherland et al., 2013). This means that advisors must be trust worthy because "the higher the source credibility and personal trust the higher the persuasion" (Sutherland et al., 2013: 98). A study by Dietze et al. (2019) shows that farmers have many more sources than just advice, e.g. to receive information on the method of tillage (see Figure 4), which include long-term experiences, colleagues and neighbours. This offers opportunities to address farmers.

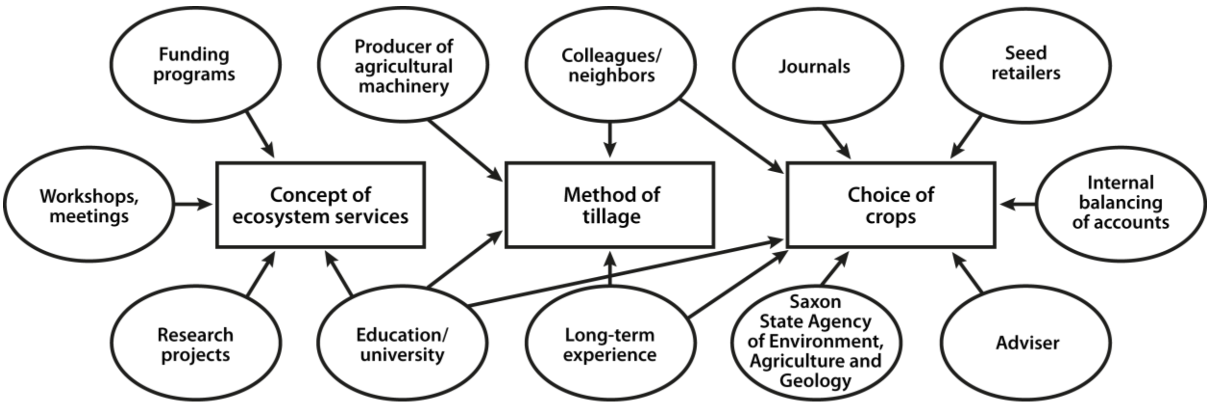

Figure 4: Sources of knowledge for farmers (Adapted from Dietze et al., 2019).

Knowler & Bradshaw (2007) identified as traditional and promising ways of distributing information and enhancing knowledge education, networks between farmers, media and exchange between farmers and other experts.

Education

Education is important to improve the skills and knowledge of farmers in realising sustainable agriculture measures (see, for example, Singh et al., 2014; Burton, 2014) because farmers who are not informed about sustainable farming measures will not adopt it in their farming system, so information is key (Knowler & Bradshaw, 2007). A literature review by Burton (2014) gives examples of studies showing that education can change attitudes towards organic farming, the environment and or the participation in agri-environmental measures. Education leads to an enhancement of technical skills and farmers are able to adopt technological innovations (Burton, 2014). Farmers are more encouraged to apply sustainable management practices if they have an awareness or perception of soil problems (Knowler & Bradshaw, 2007). This awareness can be raised at the universities and agricultural colleges.

Networks and cooperation between farmers

A prominent example for cooperation between farmers for sustainable land and soil management can be found in the Netherlands: From 2016 onwards, farmers in the Netherlands can only apply for AEM via a cooperative. The advantage of the Dutch approach is that the measures can be tailored to the local ecological conditions (Terwan, 2015). The farmers receive advice on which measures are most suitable and how to apply them. The advantage in the Netherlands is that cooperation between farmers has a long tradition (Westerink et al., 2017) notwithstanding it could also be tried in other EU member states. In addition to the collaboration between farmers, farmers receive advice and training from nature protection organisations and other groups throughout the whole process of choosing measures, defining targets and implementing the measures.

Another example of farmers cooperating with each other towards more sustainable agriculture is the Nature Friendly Farming Network (NFFN)[19], which is a group of more than 100 farmers with a new vision for the future of British agriculture is launched in January 2018, at the Real Farming Conference in Oxford, and is led by farmers across the UK with a passion for sustainable farming and nature to secure positive changes in policy, including how farming is supported by the public.

Organic producers are often part in an alternative food network that often sells directly to consumers. In high-income countries, this has consequently a positive impact on farmers' autonomy (Seufert & Ramakutty, 2017). According to the experience that different case studies in climate change and vulnerability have shown, co-production of knowledge between stakeholders and experts is recommended (Mitter et al., 2014), so it might also support the enhancement of sustainable management practices such as the SSM. Learning from others and learning-by-doing, can help to reduce the risks of implementing SSM measures.

Often farmers learn from each other through best practice examples as a spill over effect of projects: An example was given at the Soils4EU workshop: The Life project DOÑANA SOSTENIBLE (Design and Application of a Sustainable Soil Management Model for Orchard Crops in the Doñana National Park Area) supported the sustainable management of soil and water resources cultivation of olive orchards in Spain. After a while the use of new soil management techniques (minimum tillage, vegetal covers, etc.) spread through the region because farmers not involved in the project learnt from the good experiences in terms of reducing soil erosion farmers in the project made.

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[19] http://www.nffn.org.uk

Media

Information transported through printed media and literature is one of the primary knowledge sources of farmers. Widely accessible and nationally and regionally distributed information "has the advantage of reaching a broad range of producers" (Ritter et al., 2017: 3338). However, the internet is becoming more and more relevant, e.g. for the application process for subsidies or the registration of animals. It is also interesting to note that farmers from the member states who joined the EU after 2004 "are more likely to be interested in developing a range of skills and obtaining knowledge from different sources including the participation in the exchange scheme" (Zondag et al., 2015: 2). This shows that there is no one-size-fits-all approach to knowledge distribution and it is important to analyse what kinds of information are missing and how this gap can be closed.

Once new knowledge is produced, it needs to reach the farmers. Scientists can publish in farmers` magazines and raise awareness of new methods and measures. The German magazine TOP Agrar is an example where scientists contribute articles and present their latest research results. However, it requires scientists to be better trained to present their research results to a broader audience. Farm advisors prepare small films (youtube videos) of 7-8 minutes that farmers can watch. Films are offered for free and are used by farmers[20].

Exchange between farmers and other experts

Social networks (e.g. knowledge networks) are essential to strengthen the science-society interfaces and the relationship between farmers and scientists. Through such a network an exchange of practical and scientific knowledge is possible. In the USA the "climate learning network" was grounded to extend the knowledge about the adaption of agricultural practices on climate (Mitter et al., 2014). Farmers who are involved in the organic food production networks can be differentiated from those who just produce to organic standards. The former are highly networked, whereas as the latter are not involved in alternative food networks (Medland, 2016). It is important that farmers are involved in a network. There they can communicate and exchange sustainable farming practices (Singh et al., 2014). Awareness raising initiatives can also bring different interest groups, including farmers, together. One example is the Sustainable Soil Alliance[21] in the UK that was launched in 2017. It aims at addressing the current crisis in soils by bringing together scientists, innovators, policy-makers and land managers.[22]

Further research is needed to close the knowledge gaps on the effects of certain SSM measures to provide farmers with knowledge about the impact of measures and the right use of machinery or the best choice of crops, for example. The coproduction of knowledge between academic and non-academic actors can bridge this gap, because it would take better account of farmer´s needs.

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[20] Information provided by a French advisor at the Soils4EU workshop.

[21] http://sustainablesoils.org

[22] According to their website their objective "is to effect an improved political and public understanding and appreciation of soil that will lead to a reversal of land degradation and the restoration of soils to health within one generation. (…) On this basis we will engage media and stakeholders, educate the general public and lobby government for a policy framework that will bring about the transformational step change needed to support the development of healthy soil for generations to come." (https://sustainablesoils.org/our-approach)

Schneider et al., 2010 found in their study several requirements for soil conservation measures, such as they need to fit into the farming routine but also, for example, be in line with farmers' aesthetic perceptions or their value system. Several national and international project calls require the integration of stakeholders, such as farmers. The exchange between farmers and scientist can support the development of practically relevant solutions and farmers can test certain measures under scientific supervision and can learn from other farmers involved in the project. Some projects also develop specific tools farmers can use, as for example in the research project BonaRes[23] that promises to offer a service portal that provides information and decision support tools for sustainable soil management.

National and international fairs, such as the yearly fare "Green Week" in Berlin (Germany) or the Agritechnica in Hannover (Germany) are examples for exchange platform where farmers do not only meet other experts but also practitioners, advisors and scientist with whom they can interact at fair booths, panel discussions, presentations and exhibition subjects.

4.3 Administrative barriers

The **bureaucratic load of administrations and farmers increased significantly** over the last two decades with the increase in regulatory requirements and their control. Therefore, high transaction costs are often mentioned as a barrier to the introduction of new additional measures. Conflicting policies and measures are also a barrier to the introduction of SSM measures.

4.3.1 High transaction costs

An important yet understudied factor in the adoption of environmentally friendly (including soil conserving) measures is the bureaucratic load that includes inspections – this has been observed in studies of adoption (Karali et al. 2014) and abandonment of organic farming (Kirner et al., 2006) as well as the adoption of agri-environmental measures (Christensen et al., 2011; Ruto & Garrod, 2009). Lauwere et al. (2016) indicated that farmers struggle with the current national policies. These authors used the current national manure legislations as an example of difficulties for compliance.

Farmers tend to perceive **controls and fines as threats** and, therefore, are sceptical towards elective measures because they could lead to additional control. At the same time, the administration tends to be cautious about introducing new measures that might be favourable for soil protection but are linked with a lot of monitoring efforts. Pe´er et al. (2017) also found that it is not just the control but also the complexity of the measure that hinders its uptake. All efforts needed to increase knowledge and gain information, e.g. even free advisory services, need to be mentioned here, as these deserve time that cannot be spent differently (e.g. on the field) and thus is an indirect but obvious cost for the farmer. A reduction on administrative complexity can reduce costs at least it could to be considered as an option.

[23] https://www.bonares.de/services

4.3.2 Measure design conflicting SSM

Some of these measures might be seen as impractical for the farm structure (certain tillage practices that require large machinery) and are a further barrier for implementation. The reduction or the total ban on herbicides could lead to more intensive mechanical weed control (tillage). However, intensive tillage can lead to erosion, especially on erosion prone sites such as the Alps or other mountain regions. Sometimes strict timelines also counteract SSM: Some AEM, for example, have a strict timeframe for certain activities such as mowing. Unexpected weather events such as long rain periods may not allow the farmer to enter and mow the field until the deadline without harming the soils (compaction) but the farmer has to fulfil the contract. The farmer may apply for derogations but this implies additional administrative efforts.

4.3.3 Solution

There is no one-size-fits-all approach for all regions but regionally adapted measures that have a clear positive impact on soils. The AEM already allow the regional adaptation of measures. Moreover, the AEM take relevant stakeholders on board, such as farmers who know the conditions and can judge the applicability of measures. Such an approach is cost-intense, it requires coordination, time and human resources.

4.4 Political barriers

The objectives of policies are sometimes contradictory, for example, between the renewable energy targets of the EU and their Member States and the objectives (environmental and social) by the second pillar of the CAP, such as the reduction of chemicals application, conservation on biodiversity and the maintenance of traditional agricultural landscapes (Troost et al., 2015). But also trade policies and land property rights have the potential to lead to soil management that has negative impacts on the soil.

4.4.1 Renewable Energy Directive

The Renewable Energy Directive (2009/28/EC) aimed to extend renewable energy to 20% by 2020. It´s successor, the revised Renewable Energy Directive (EU) 2018/2001 sets a binding target of at least 32% renewable energy for 2030 with a potential increase after a review in 2023. The growing demand of biomass as energy source increases pressure on land, with potential negative impacts on biodiversity through an intensified land use. Especially agriculture, including biodiversity-rich land, is increasingly under pressure. Bioenergy production may push food production also into uncultivated areas which may have negative impacts on natural habitats. Also, the increasing land demand for biomass production leads to an increased pressure on the availability of land for food production (Pedroli et al., 2013).

In case of policy contradiction or competing subsidies, farmers, not only in Germany, will most likely choose the most financially attractive option. Contracts for biomass with bioenergy plants often last for several years, even up to 20. In times of fluctuating market prices these contracts offer financial security. Moreover, farmers receive additional subsidies for cultivating biomass for bioenergy. With the reform of the European energy policy implemented through the Renewable Energy Directive 2018/2001 the incentives for an ever-increasing biomass production are reduced.

However, the current amount of biomass production will probably remain even though there is now a limit for the biofuels made from crops or oilseeds.

The German Renewable Energy Act had an additional negative effect, which is an increase in land prices (see, for example, Tietz, 2018; Ritter & Hüttel, 2016). In Bavaria the prices for agricultural land more than doubled between 2007 and 2016 (Tietz, 2018). The Renewable Energy Act is not the only reason but an important one. With higher prices for land farmers need to increase their revenues to cover the costs. New investments to change the farming systems and the risk of income loss add up to this tendency of increasing prices for land.

4.4.2 Trade policies and land property rights

Another political barrier, mentioned during the Soils4EU workshop, is the trade system: It was mentioned that the European market receives low cost products from the world market that are not of the high European standards from abroad, which makes it difficult for farmers to compete with these products. Especially, but not exclusively, in East European countries, such as the Czech Republic, the form of redistribution of land property rights and land use rights after the political turnover “impact on the types of degradation problems and impede the implementation of suitable measures” (Prager et al., 2012: 71). Another example of conflicting policies is, for instance, irrigation development policies that have induced soil salinisation (Prager et al., 2011).

4.4.3 Solution

It is necessary to balance the effects of different policies and to set priorities towards one goal. This could be solved through an agreement on a strategic policy framework that includes objectives and strategies such as supporting the implementation of SSM measures and that ensure that new directives and regulations are not contradictory. This requires cross-sectoral cooperation across DGs and ministries in EU member states. Moreover, the diversity of climatic and soil conditions across Europe needs to be acknowledged.

4.5 Cultural and social barriers

Cultural and social barriers such as mental models or demographic indicators are less tangible than the former barriers. However, they seem to be as relevant as the others. One of the most common barriers for implementing SSM is the **characteristics and attitudes of farmers**. For example, age can influence decision-making as it is an index that determines attitudes and beliefs. Of course, these factors are more difficult to be address by specific measures but understanding mental models, for example, shows why a general policy with the objective of promoting behavioural and institutional change (Prager et al., 2011) will face a number of practical limitations in the farming community.

4.5.1 Mental models of society and farmers

The assumption that farmers are profit maximisers is central in many agricultural models, but observations in different studies found out that this is not true in all cases (Edwards-Jones, 2006). A farmer who has the productivist role uses his land in its full potential.

The main difference between 'good' and 'bad' farmers is the quality of crops and livestock. This is judged by two criteria – first: the physical appearance of the crop or animal and second: the crop yield per hectare (Burton, 2004). Thus, a farmer becomes a 'good farmer' through self-improvement. This includes the improvement of mechanical, motoric, agricultural practices and managerial skills. Burton et al. (2008: 23) see a relation between good farming and economic efficiency: "All symbols of good farming ability relate to some extent to the economic efficiency of the farmer – that is, all originate from the concern that farm management should involve minimising waste and maximising production".

The importance of cultural and social factors in adopting organic farming, agri-environmental measures and other environmentally friendly practices is high. For instance, Burton et al. (2008) stress the importance and characteristics of the **image of a 'good farmer'** and the (in)compatibility with particular practices as crucial to the understanding of the 'cultural resistance' towards AEMs. Here, productivist attitudes towards farming can be a major obstacle (Mills et al., 2017; Mann & Gairing, 2012). On the other hand, Riley (2016) shows with results from a long-term study that over time, many farmers who participated in AES, engaged more in proactive conservation management than prior to their participation.

Farmers´ decisions about the choice of agricultural practices depend not only on profit but also on many other factors, such as social (**cultural beliefs, social norms and embeddedness, personal values) or ecological.** The background of a person, including culture, knowledge or experience is very important because it determines how they see the environment around them (Prager & Curfs, 2016). Attributes of farmers, such as personality, intentions, beliefs, values, skills, knowledge and attitudes influence the implementation of measures listed under SSM (see, for example, Ritter et al., 2017; Sattler & Nagel, 2010). It also explains why some farmers are averse to changes.

The Catch-C project conducted a behavioural approach with farmers to identify drivers and impacts in implementing sustainable soil measures. The results show that farmers are mostly determined by individual beliefs (EC, 2015). Farmers' attitudes towards soil protection have also been described and reported as relevant determinant for the application of soil conservation practices by Wauters et al. (2010). For instance, when it comes to adopting no-tillage schemes, farmers' attitudes towards chemical plant protection (particularly glyphosate) is a determinant factor. A study by Prager & Curfs (2016) shows that some Spanish farmers do not consider sustainable soil management as an important part of their mental models and do not see ploughing as an increasing determinant for soil erosion. Farmers orientate their management practices rather by the actions of their neighbours than by the recommendations of scientists. For example, the farmers in Spain implemented grazing as a mutual arrangement with their neighbour and do not plough anymore (Prager & Curfs, 2016). Social backgrounds such as colleagues or family as well as printed media or discussion groups affect decisions on agricultural practices of farmers (Ritter et al., 2017).

The cultivation of energy crops on arable land leads also to an internal conflict of the perspective of farmers between food production and energy-crop cultivation. After the Second World War, farmers were encouraged to maximize the output, also through the newly established Common Agricultural Policy, to reduce the dependency of food imports. Food provision was the key task. This perception changed over the last two decades, since many farmers are **not only seen as food producers anymore but also as energy supplier**. Through the land use change caused by increasing bioenergy production, can lead to a decline in food production (Steinhäußer et al., 2015).

4.5.2 Demographic factors

Demographic factors such as age, sex and gender can have an effect on management strategies, even though this is highly disputed in literature if the correlation is caused and if so in which way. Aged farmers with no successor are less prone to change and experiment new practices; land abandonment usually originates soil and habitats degradation. New generations have the opportunity of start with and spread new approaches and do things differently, but the interest of young people to become a farmer is low.

Younger farmers were raised in a time, when environmental aspects receive increasing attention. While some studies found out that younger farmers are more encouraged to implementing sustainable management measures than older farmers (see, for example, Murphy et al., 2011; Boon et al., 2010; Rodriguez et al., 2008), other studies did not find age as an influencing factor (Egri, 1999; Siebert et al., 2010). Moreover, Defrancesco et al. (2008) found for AEM that older farmers had a higher share in participation than younger ones.

4.5.3 Self-image of farmers

The social image and self-esteem is also crucial for farmers and can be a true barrier towards SSM. Farmers decide which agricultural practices they implement based on the cultivation practices of their peers, traditions and also economic considerations. Often, the farm is not only a working place for farmers but the basis of a certain way of life.

During the Soils4EU workshop it was made clear that farmers are not garden keepers, nor worm breeders, nor environmental guards, their profession is to produce food. For a very long time, especially after World War II farmers were seen as a cornerstone of the society because they feed the society and they received subsidies for increasing production. Today, many feel betrayed, because decades ago they were asked to produce food and now they are told that the pure production focus is not good anymore and they should produce more sustainable. Today, there is a lack of support of many parts of the European society to farmers for overcoming some of their problems and allowing them for change towards a more sustainable agriculture.

Farmers are businessmen and -women and follow markets demand. It is of upmost importance that society understands farmers, because many would like to be more sustainable, and they usually state that they are proud to contribute to improve ecological conditions. In Switzerland, farmers are by law responsible for delivering ecosystem services. A system for rewarding for actual ecological services paid by farmers will help to produce these services.

4.5.4 Solution

To better understand the role of age, sex and gender **more research is needed**. The existing analyses are already rather old and provide no clear hint of which factors are really relevant. At the moment the reader finds arguments for both – that age and gender have an effect and also the opposite. For policy makers this is too vague to make decisions. However, the requirements for support will probably differ between regions. The existing measures to support young farmers who are 40 or younger at least for 5 years after taking over the business or founding a farm could address this barrier.

Distribution of information is also needed, such as through advisory services, farmer cooperations, and also policy measures such as agri-environmental measures that request the cooperation between farmers, as is the case in the Netherlands and partly also in Austria.

The discussion during the Soils4EU workshop clearly illustrated that farmer to farmer advice is a very important key for promoting SSM: Experiences of the participants have shown that farmers are more willing and interested to apply certain measures when the information and/or advice is provided by another farmer. Also actions taken by farmers independently from any external actors were mentioned as good examples for bottom-up initiatives: In Southern Spain farmers experienced soil erosion on their land and formed an association to address the issue of erosion. This association then hired an advisor from Argentina who supported the farmers of the association to prevent erosion on their land.

At the moment, it seems that many policies do not consider adequately characteristics and motivations of farmers and the fact that farmers have not only the goal to maximise profit but to link economic, social and environmental objectives in their farming system. Therefore, Vuillot et al. (2016: n.p.) comment has to be taken seriously: "[F]uture policy should take into account the complex role of various constraints in farmers' mental models and consider alleviating them". It calls for subsidiarity and policies that design measures that are tailored to the needs of the regions and the farmers.

5. How can we overcome the barriers towards the implementation of sustainable soil management measures?

Chapter 4 has shown a number but not an exhaustive list of barriers towards SSM implementation. The analysis does not claim a hierarchy of barriers and that all the barriers mentioned are relevant and can seriously hinder the implementation of SSM. The solutions to overcome these barriers differ based on the type of barrier, although most of them require at least some initial financial support. The financial barriers can be overcome by financial support, i.e. subsidies, tax releases etc., but also by cooperation between farmers or insurance. Cooperation can also help to overcome other barriers such as the lack of knowledge. A different measure is needed for overcoming most of the administrative barriers. In the case of lack of support from the administration, high transaction costs and conflicting policies, structural changes are required. This is also linked to financial support (e.g. more staff in the administrations for providing advice) but it first of all requires political will to initiate a change. The cultural and social barrier is the most persistent and most difficult to address. Mental models, traditions and demographic changes do not change overnight. They require education, knowledge distribution as well as time and also funding.

Europe is heterogeneous and so are its farmers. It was shown in Chapter 4 that the barriers do not apply to all farmers to the same extent. It also means that there is no silver bullet to overcome these barriers. Some measures might work in one case but not in another. Moreover, solutions need to be surely linked with each other. For example, if there is a policy providing financing, but there is not a training/corporation/advisory system, the financing programme may fail. Finding the right approach to overcome a barrier requires an analysis of what the relevant barrier is, why it is a barrier and how it could be overcome. Despite the claim for case-specific actions to address barriers some general recommendations can be drawn, as shown in the next subsections.

5.1 Strategic policy framework

Based on the findings of the report, a strategic policy framework is needed to implement SSM. A strategic policy framework could "(a) conceptualise soil issues (including, where appropriate, common definitions on good status); (b) set out priorities and targets; (c) define monitoring parameters and desired objectives; and (d) try to define the possible role of different policy instruments in delivering good soil status" in an integrated manner (Frelih-Larsen et al., 2017: 12). Such a framework also needs to address the massive external drivers such as agricultural commodity markets, increasing human populations demanding more and cheaper foods, and powerful supply chain members forcing farmers into a corner, which results in unsustainable farming practices. The whole supply chain needs to be addressed, from multiple producers over the processing industry and food stores to consumers. Without addressing these underlying drivers through awareness raising and the internalization of external effects in market prices.

In addition, the strategic policy framework should include policy reforms towards supporting the implementation of SSM measures, including regulatory but also economic instruments in a policy mix, such as financial incentives at regional and national levels or tax reduction tailored to the SSMs. It could also support the mobilisation of additional funds (e.g. private) and collaboration activities between farmers.

A strategic policy framework needs to support measures that address specifically regional or even local specificities (e.g., recognize the multi-functionality of soils and diversity of farms): Pe`er et al. (2017: 115) found that “[r]eviews and case studies indicate effectiveness to be highest when AECM are landscape-targeted, regionalised to the conditions of the sites, and focusing on non-productive areas such as natural habitat and field margins.” This finding is supported, for example, by Emery & Franks (2012: 218) who found out for England that collaborative agri-environmental measures “are likely to gain support from farmers where they are seen to offer greater flexibility; scope for farmer involvement in scheme design; locally targeted and clearly defined aims, and; demonstrable benefits that can be monitored as a record of success.”

Future policies also need to take into account “the complex role of various constraints in farmers’ mental models and consider alleviating them” (Vuillot et al., 2016: n.p.). Another focus has to be the reduction of incentives through counteracting policies, such as energy policies that encourage farmers through long-term contracts with bioenergy producers to cultivate monocrops such as maize or take off crop residues from the field. The reform of the European Energy Policy already includes a limit for the biofuels made from crops or oilseeds but does not fully abolish the incentives.

5.2 Strengthening advice to farmers

The variety of personal and socioeconomic barriers suggests that efforts to promote soil conservation in agriculture will always have to be adapted to the local level – the farmers. However, farmers have different profiles and they must be free to choose the measures for their specific farm type. An important source of (practical) knowledge transfer to local farmers is agricultural advisory services (see, for example, Ingram, 2008; Knowler & Bradshaw, 2007; Bager & Proost, 1997). Advisory services are essential to inform farmers about SSM practices and new funding incentives. Informational policy instruments are necessary for a successful implementation of mandatory and incentive-based policy instruments (Prager et al., 2011). Strengthening advisory services requires approaches to covering the costs of advice including the transaction costs of farmers.

Advice is important because it allows for farm specific adaption. Especially in case of conservative and risk averse farmers, it is important that measures fit in the existing farming system. Also, different strategies need to be applied for farmers who are i) already applying SSM because they already have an understanding and are probably more open, ii) farmers who have no experience with SSM but are interested and iii) farmers who object to SSM because it does not fit their farming scheme, they are risk averse or have other reasons.

Moreover, advisory services need to be rooted in organisations that are easily accessible for farmers. This includes that the public administration can serve as a contact point but in this case it needs to be independent, and it should be avoided that the administration is at the same time adviser on SSM and the control authority. There should be a crystal clear separation of advice and monitoring. In case privatised advice dominates, sometimes initial funding has to be provided.

Advice for enhancing SSM also requires the education of advisors. During the Soils4EU workshop it was mentioned that advisors are sometimes more conservative than famers themselves and that they do not automatically promote innovation or changes towards more sustainable farming. Training for advisors could be offered at university, in general education, through the administration, advisory services themselves, associations etc.

It is necessary to try to inform and convince farmers about suitable measures for SSM, but the discussion during the Soils4EU workshop showed that better than informing farmers is to engage them. They do have the - often still traditional - knowledge that is valuable and necessary to ensure sustainable farming. Observations from workshop participants show that farmers are proud when they can contribute to sustaining ecological functions of the soil and inform other farmers about suitable measures.

5.3 Increase research and development

Research is needed on the effects of SSM measures and the trade-offs they might imply. Solid information is especially required to convince farmers as they tend to be risk averse but also because a change in management measures is linked to a financial risk that a farmer wants to keep as low as possible, as every business person would do. Besides research, technological development is also required to find new ways of low-cost solutions for SSM, such as machinery or fertilisation techniques. However, research and development are not effective when the results and innovations are not transferred to the farmer. Improving not only science-policy but also science-society interface to increase the transfer of scientific knowledge into practice and investment in science to close knowledge gaps, including long-term studies is therefore also needed.

As mentioned in the report, not all measures are applicable across Europe to the same extent. This means that different approaches are needed for different regions. To identify the most efficient and at the same time accepted measures requires the coproduction of knowledge of farmers, politicians and scientists.

5.4 Ensuring financial support

Strengthening advisory services and initiating information campaigns requires a budget. Moreover, approaches such as tax reductions or investment support (e.g. loans) that have the potential to set incentives for farmers to take up measures require some financial support. This is not to say that in any case additional money is requested but existing funds and programmes, e.g. within the CAP, could be reshuffled to support the implementation of SSM measures. In that sense the CAP money would be spent to pay for the provision of public goods rather than actions taken at farm-level. In the long-run even extra support could pay off when an increasing soil quality leads to increasing yields, more biodiversity and ecosystem services.

As it is quite likely that the CAP funding will decrease over the coming decades, also alternative financial strategies need to be sought. Examples are funds from the industry safeguarded by NGOs such as the WWF as illustrated in section 4.1.4. As these are private initiatives, a disadvantage is that neither the standards of the measures can be controlled nor can rights of farmers be easily protected and defended. For example, contracts between a company and a farmer can put even more pressure on farmers than legal obligations to keep certain quality standards and/or produce a certain quantity.

6. Conclusions

This report outlines the many positive environmental, ecological and social impacts of SSM and how the concept is already applied. Progress with regard to more sustainable soil management practices has been achieved by many farmers in Europe, but not all European soils are sustainably managed. A number of barriers exist for farmers to adopt SSM. When interviewing farmers on soil policies, Claus et al. (2017) report on the need for more simple and flexible legislation. The implementation of adequate financial incentives and the cooperation with advisory services for awareness-raising have also been quoted as success factors for an EU soil protection policy.

The report does not claim a hierarchy of barriers (e.g. the financial barriers are more relevant than the technical) because which barriers are most relevant depends on many factors such as the farming system, access to knowledge and information or mental models that exist towards SSM. Thus, the report does not prescribe the one solution for overcoming the barriers to SSM. It rather highlights the diversity of farmers and farm types, climatic and natural conditions, cultural backgrounds, economic situations and available advisory support as reasons of barriers and this leads directly to the diversity of approaches that are necessary to overcome the barriers (Figure 5).

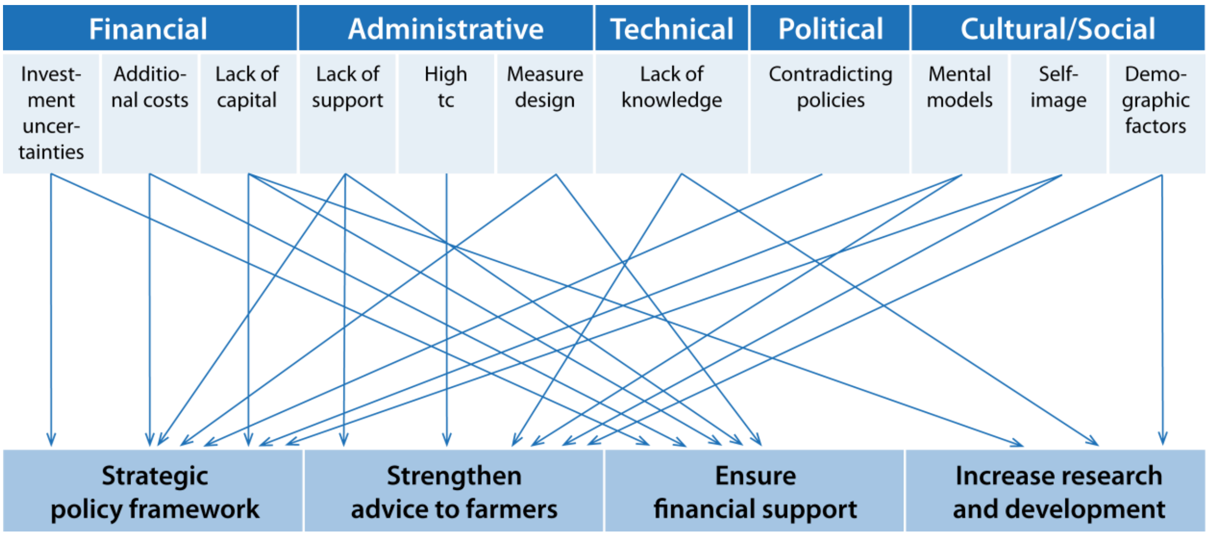

Figure 5: Overview of barriers and possible solutions to overcoming these barriers.[24]

From the description of the barriers some general recommendations can be derived. Strategies are urgently required that lead towards a strategic policy framework to ensure SSM, ensure that farmers receive advise and get the technical knowledge needed (e.g. through support of advice that is professional and action oriented or through exchange of success stories and examples). Strategies also have to address the whole production chain from multiple producers to consumers and raise awareness at all levels and support research and development on effective SSM.

[24] The abbreviation tc is short for transaction costs.

The report also recommends that for overcoming several barriers, financial support must be provided. This is not to say that it is the only approach towards the barriers. Some measures can be implemented without extra financial support. However, it cannot be overseen that financial support is key to overcoming the barriers, especially for cushioning the economic risks or for intensifying advice which was also highlighted as crucial. A transition towards SSM will most likely not be achieved at low cost, but when looking at the positive effects it becomes clear that in the long-run it will pay back. Moreover, a lot of money is already available for the CAP. This money could be reshuffled to support the implementation of SSM measures. In addition, private money can also support SSM however fair and reliable contracts for farmers are required.

Several decisions need to be made by politicians, but some other measures can be supported by advisory services, associations, farmer initiatives and scientists. One action is crucial for all of them: Increasing communication and respect between politicians, scientist and farmers to engage in an open dialogue with one another.

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