Towards climate-smart sustainable management of agricultural soils

Deliverable 2.1

Synthesis of the impacts of sustainable soil management practices in Europe

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AUTHOR:	A. Paz, C. Carranca, J. Miloczki, M. C. Gonçalves, N. Castanheira, R. Mihelič, M. Carrasco and C. Vicente.
CO-AUTHOR:	A. Don, B. Vrščaj, B. Sanchez, B. Huyghebaert, D. Stajnko, D. S. Intrigliolo, E. Mason, G. Garland, H. Känkänen, H. Spiegel, I. Castro, J. Lesjak, J. de Haan, J. Mellon, J. Vilcek, J. Miloczki, K. Skaalsveen, K. Meurer, K. Sándor, L. Munkholm, L. Kukk, M. de Boever, M. Pulido-Moncada, P. Nino, R. Ramsey, R. Wawer, R. Kasparinskis, S. Madenoğlu, S. Higgins, T. Salo, V. Feiza, V. Penizek, W. Vervuurt.
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ABSTRACT

This synthesis identifies the knowledge about the sustainable soil management practices and their biophysical and socio-economic impacts, as reported by the research teams of the different EJP SOIL participating countries. Most reported practices were in the group of “Crop and cropping systems”, followed by the group “Soil tillage and cover”. The three most reported impacts related to sustainable soil management practices were “Soil quality”, “Nutrients in the soil”, and “Soil Structure”, while the impacts “Desertification”, “Readiness for use”, and “Other socio-economic” were the less reported.

The impacts of sustainable soil practices were also related to the EJP SOIL soil challenges. The three most reported challenges were “Enhance nutrient use efficiency”, “Maintain/increase SOC”, and “Improve soil structure”, while “Avoid acidification”, “Avoid salinisation/alkalinisation”, “Avoid N_2O and CH_4 emissions from soils” were rarely reported. These results were related to varying levels of knowledge or awareness about the sustainable soil practices and their impacts. The synthesis identifies the need for further knowledge on some impacts and challenges, such as, for instance, evidence of practices contributing to increase carbon in deeper soil layers, and of practices to decrease greenhouse gas emissions from agricultural soils.

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List of acronyms and abbreviations

ALN - Alpine North

ALS - Alpine South

ANA - Anatolian

ATC - Atlantic Central

ATN - Atlantic North

BOR - Boreal

CON - Continental

ER – European region

ENZ - Environmental Zone

LUS - Lusitanian

MDM - Mediterranean Mountains

MDN - Mediterranean North

MDS - Mediterranean South

NEM - Nemoral

PAN - Pannonian

SOC – Soil organic carbon

SSP – Sustainable soil management practices

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1. Executive summary

This report provides a synthesis of the impacts of sustainable soil management practices (SSP), assessed by the research teams of the EJP SOIL participating countries, as a result of task 2.4.1. The information was provided by twenty three countries, by completing a questionnaire concerning the knowledge availability about SSP, their biophysical and socioeconomic impacts, and the related EJP SOIL challenges. The synthesis provides an analysis of the level of reported SSP, impacts, and challenges, for the overall contributing countries, for Environmental Zones and for European Regions. The high or low level of reporting of the SSP and their associated impacts and challenges can be related to varying levels of knowledge or awareness about these relations.

The knowledge over all the SSP and their impacts is very broad and difficult to tackle within this task alone. As a result, the following represent only some of the key findings of the synthesis:

- There was a low level of reported knowledge about the reduction of N_2O and CH_4 emissions from agricultural soils, considering the overall relevance of this challenge in the context of climate change mitigation. On the other hand, SSP contributing to maintaining and increasing SOC had a high level of reported knowledge. This can be due to the fact that emissions reduction has not been a central question for farmers, agronomists and researchers, and indicates a need for more research and/or dissemination of practices addressing this challenge.
- The effect of SSP on “C storage in the soil” is mainly reported for the top soil layers. In deeper soil layers, few inputs are reporting that no significant differences or even decreases with depth. Information provided by participating countries indicates that further knowledge is needed on what extent do sustainable soil management practices impact “C storage in the soil”.
- Reports on the impact “Farmers’ profitability“ indicate the need for more quantitative evidence on the adoption of SSP and, eventually, additional incentives at the national/regional/EU level would help farmers to adopt these practices.
- The SSP related to “Water management” is the most important group in Southern Europe, but knowledge about irrigation and water use efficiency is reported in every European Region, with several countries in Western Europe identifying interest in this SSP related to adaptation to climate change.
- Even though several countries have large parts of their territories susceptible or at risk of desertification (mainly in Southern Europe), desertification was the less reported impact, with marginal reported knowledge, even in the referred region. This result indicates the lack of studies considering the integration of the different processes leading to desertification and the SSP to counter it.

2. Introduction

EJP SOIL - Towards climate-smart sustainable management of agricultural soils, is a European Joint Programme aimed at enhancing the contribution of agricultural soils to key societal challenges, such as climate change adaptation and mitigation, sustainable agricultural production, ecosystem services provision, prevention and restoration of land and soil degradation, and biodiversity maintenance. The EJP SOIL consortium is composed of 26 European research institutes and universities in 24 countries.

This report analyses the inputs given by 23 participating countries and 24 research bodies for task 2.4.1 "Synthesis of the impacts of sustainable soil management practices" which, along with four other stocktakes and synthesis, is part of task 2.4 "Synthesis of key soil related issues in the EJP SOIL countries in order to identify gaps and design region relevant research", included in Work Package 2 "A roadmap for Agricultural Soil Management in Europe".

The aim of this synthesis is to collect systematic information from all countries in EJP SOIL on the biophysical and socio-economic impacts of sustainable agricultural soil management practices (SSP). The results will give guidance to the development of a roadmap that describes the current state and knowledge gaps in agricultural soil management in Europe and will form the base to develop calls for research projects in the 2nd year of EJP SOIL and beyond.

According to FAO (2015)[1] "Soil management is 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 starting point of this work focuses on the practices which have evidenced impacts, either in scientific literature or other sources.

The report presents the methodology used to collect and analyse the information (section 3), the results are organized in three main sections: practices (section 4.1); impacts (section 4.2), and challenges (section 4.3). Inside each section, results are organized geographically considering both Environmental Zones (ENZ) and European Regions (ER). Finally, the limitations and conclusions of the synthesis are presented in sections 5 and 6. As participating teams were asked to provide quantitative information whenever possible, a comprehensive summary of the reported quantified impacts of SSP is provided in Annex I.

[1] FAO, 2015, Voluntary Guidelines for sustainable soil management.

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3. Methodology and data source

3.1. Data Collection

The information used in this report was collected through a questionnaire sent to the twenty six research teams in the twenty four countries participating in the EJP SOIL. Each research team compiled the information for filling the questionnaire by consulting scientific databases, knowledge repositories, stakeholders, and according to their specific contexts. In the questionnaire, the research teams could choose between a total of 30 predefined SSP grouped in four management groups or identify other specific SSP within each of these groups. The four management groups and SPP are listed in Table 1. For each SSP, the teams were asked to add information relatively to the specific context of application of the SSP, such as the level of deployment.

Table 1. List of predefined SSP for each management group, as presented in the questionnaire.

Management group	Soil tillage and cover	Crop and cropping system	Nutrient management and crop protection	Water management
SSP	No till	Crop rotations	Use of organic fertilizers (green- and animal manure, organic by-products and crop residues, biochar, compost)	Determination of the Water Use Efficiency (photosynthetic WUE, WUE of productivity, water footprint)
	Direct seeding	Associations/intercropping/multiple cropping/sequential crop	Use of biofertilizers (biostimulants, nitrogen-fixing microorganisms, mycorrhizae)	Efficient irrigation systems (drippers or micro-sprinklers, subterranean irrigation, distribution efficiency)
	Non-inversion/reduced tillage	Cover/catch crops	Use of soil amendments for buffer capacity and pH (organic, inorganic)	Irrigation scheduling (based on models for water and solute transport, soil water balance, water deficit irrigation)
	Contour ploughing	Use grassland/ pasture with legumes	Methods for efficient fertilization (fertilizer recommendation, models to estimate soil nutrient balance)	Drainage systems, management of water table and flooding
	Terrace farming	Perennial crops	Mechanical weeding	Monitoring of soil salinisation
	Controlled traffic farming	Mulching	Precision of herbicide application	Monitor the quality of irrigation water (for salts, nutrients and potential harmful substances)
	Low pressure in tires	Permanent soil cover	Other (specify)	Improve water storage capacity, infiltration and reduction of runoff
	Reduction of soil compaction	Vegetated/grass buffer strips		Other (specify)
	Other (specify)	Hedges		
		Other (specify)		

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For each SSP, the research teams were asked to identify up to three impacts, to describe those impacts in a quantitative manner, whenever possible, the applicable ENZ, and list up to three references. The impacts could be described as positive, negative, or neutral, which can be used to describe trade-offs between impacts for a given SSP. In order to identify the impacts in a harmonized manner, the teams choose among the following 11 impact categories, which include biophysical, chemical, and socio-economic impacts:

- Nutrients in the soil
- Carbon storage in the soil
- Soil structure
- Soil quality
- Soil biodiversity
- Adaptation to climate change
- Desertification
- Other biophysical
- Farmers profitability
- Readiness for farmer's use
- Other socio-economic

For each identified impact, the research teams could assign the main related soil challenge, according to the predefined EJP SOIL soil challenges[2]:

- Maintain/increase SOC
- Avoid N_2O and CH_4 emissions from soils
- Avoid peat degradation
- Avoid soil sealing
- Avoid soil erosion
- Avoid salinisation and alkalinisation
- Avoid acidification
- Avoid contamination
- Improve soil structure
- Enhance soil biodiversity
- Enhance soil nutrient use efficiency
- Enhance water storage capacity

[2] The EJP SOIL soil challenge "Avoid soil sealing" and "Avoid peat degradation" were not related to any sustainable agricultural soil management practice, therefore are not shown in the figures of this synthesis.

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EJP SOIL has adopted the soil concept framework in Figure 1. This figure illustrates the multiple links between the EJP SOIL Domains and local land management choices that can influence the elements of climate-smart sustainable agricultural soil management and how such management choices might impact primary soil functions and agricultural soil challenges.

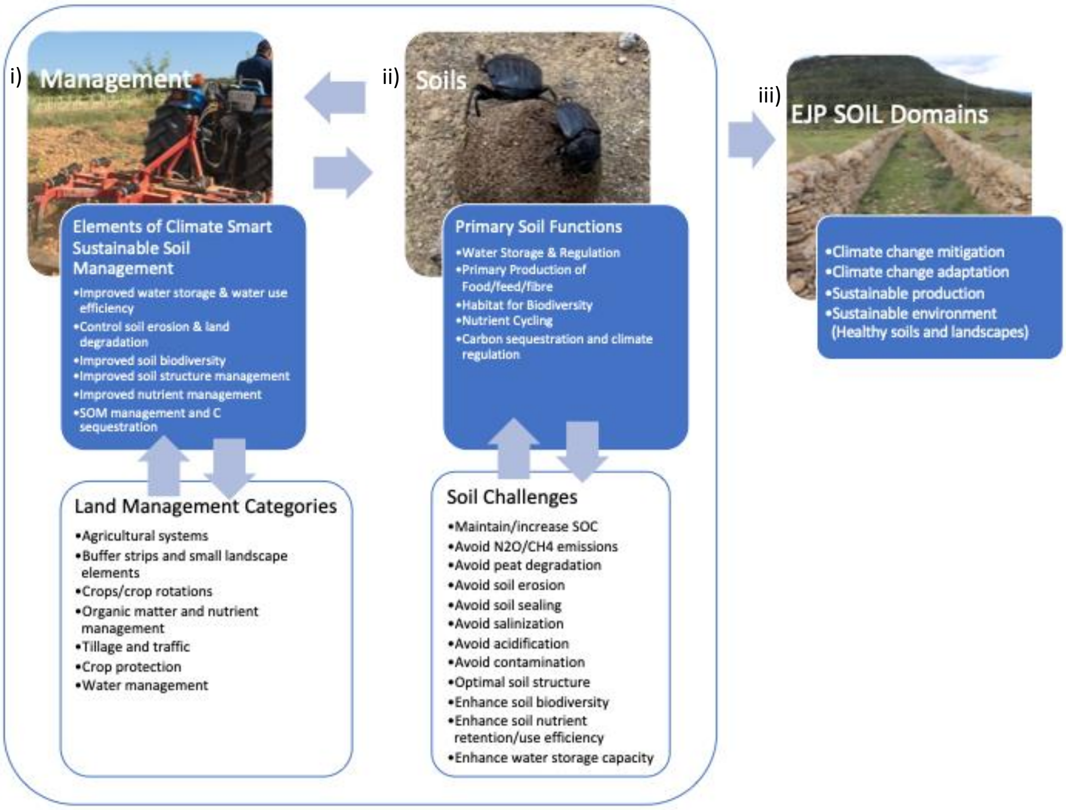

Figure 1. Soil Concept Framework. Diagram illustrating the links between: i) how local land management choices can influence the elements defining climate-smart sustainable soil management; ii) the link between primary soil functions and soil challenges; and iii) how optimized interactions between soil functions and soil management will lead to achieving the goals in the EJP SOIL Domains.

3.2. Geographical analysis

Twenty-four teams in twenty-three EJP SOIL participating countries provided information for the synthesis (Ireland was the only EJP SOIL participating country that did not contribute to the synthesis). The SSP and their impacts may acquire varying relevance according to the pedo-climatic and geographical contexts. In order to analyse these differences, the results were organized according to Environmental Zones (ENZ) and European Regions (ER). The ENZ constitute a spatial classification which was chosen by the teams from other tasks in EJP SOIL to account for environmental characteristics. The classification is a result of twenty most significant environmental variables, resulting from a principal component analysis, which produced thirteen ENZ for Europe, according to

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Figure 2 (Metzer et al., 2005[3]). In order to analyse the geographical differences, the results were also analysed according to European regions (ER), defined as following:

- Northern Europe (Denmark, Norway, Sweden, and Finland)
- Central Europe (Austria, Czech Republic, Estonia, Germany, Hungary, Slovakia, Slovenia, Poland, Lithuania, Latvia, and Switzerland)
- Western Europe (Belgium, France, Netherlands, and United Kingdom)
- Southern Europe (Portugal, Spain, Italy, and Turkey)

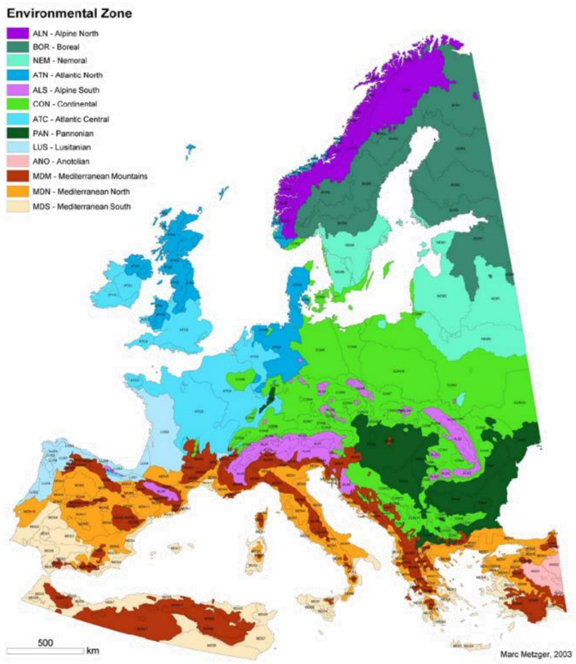

Figure 2. Environmental zones (ENZ) of Europe according to Metzger et al. (2005). In this synthesis the following ENZ are represented: Alpine North (ALN); Boreal (BOR); Nemoral (NEM); Atlantic North (ATN); Alpine South (ALS); Continental (CON); Atlantic Central (ATC); Pannonian (PAN); Lusitanian (LUS); Anatolian (ANA); Mediterranean Mountains (MDM); Mediterranean North (MDN); Mediterranean South (MDS).

[3] Metzger, M.J., Bunce, R.G.H., Jongman, R.H.G., Mücher, C.A. and Watkins, J.W. (2005). A climatic stratification of the environment of Europe. *Global Ecology and Biogeography*, 14, pp. 549–563.

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3.3. Data harmonization

In some cases, there were variations in the criteria used by the research teams to categorize practices, impacts and challenges. As a result, some harmonization procedures were carried out in order to obtain comparable data. The following rules were used for harmonization:

- Agroforestry practices were categorized under “Other (crops and cropping system)”.
- Organic farming practices related to fertilization were categorized under “Use of organic fertilizers” in the management group “Nutrient management and crop protection”.
- Impacts related to reduction N_2O and CH_4 emissions were classified in the impact “Other biophysical”.
- The impacts related to “soil erosion” were categorized under impact “soil quality”.
- “Soil quality” was also used for describing multiple combined impacts.
- Impacts referred to the biodiversity of the entire ecosystem and not exclusive soil biodiversity were categorised as “Other biophysical”.
- “Adaptation to climate change” focused on adaptation measures and excluded impacts related to mitigation of climate change (e.g. emissions reduction), which were categorised as “Other biophysical”.

4. Results

The results are organized in three sections:

- analysis of SSP
- analysis of the impacts
- analysis of the challenges

In each of these sections, the results are presented at three levels:

- overall results for contributing countries
- results by ENZ
- results by ER

Inside their boundaries, the countries include a different number of ENZ (see Figure 1), as a result they can report the same SSP for more than one ENZ. To account for these potential repetitions, when analysing the SSP at overall or country level, they are accounted only once per country.

When analysing the SSP, impacts and challenges at ENZ and ER level, the number of reports was normalized to a relative frequency and expressed in percentage. This is because the ENZ and ER are composed of different number of countries, which inserts a bias in the absolute values for ENZ and ER which include more countries.

Some of the figures and results presented in this report are also visible in interactive format, allowing for a more detailed and personalised analysis, available online at the following link:

https://public.tableau.com/app/profile/iniav.projetoist2020/viz/INIAV_16109918326030/Home

Figure 3 shows one example of such a possible analysis, in which the SSP "Organic fertilizers" is selected and it is possible to analyse the details about the associated impacts and challenges and countries that reported them. Also, it is possible to analyse by ENZ or ER the associated impacts and challenges of the SSP "Organic fertilizers" allowing the user to perform the analysis at the three levels.

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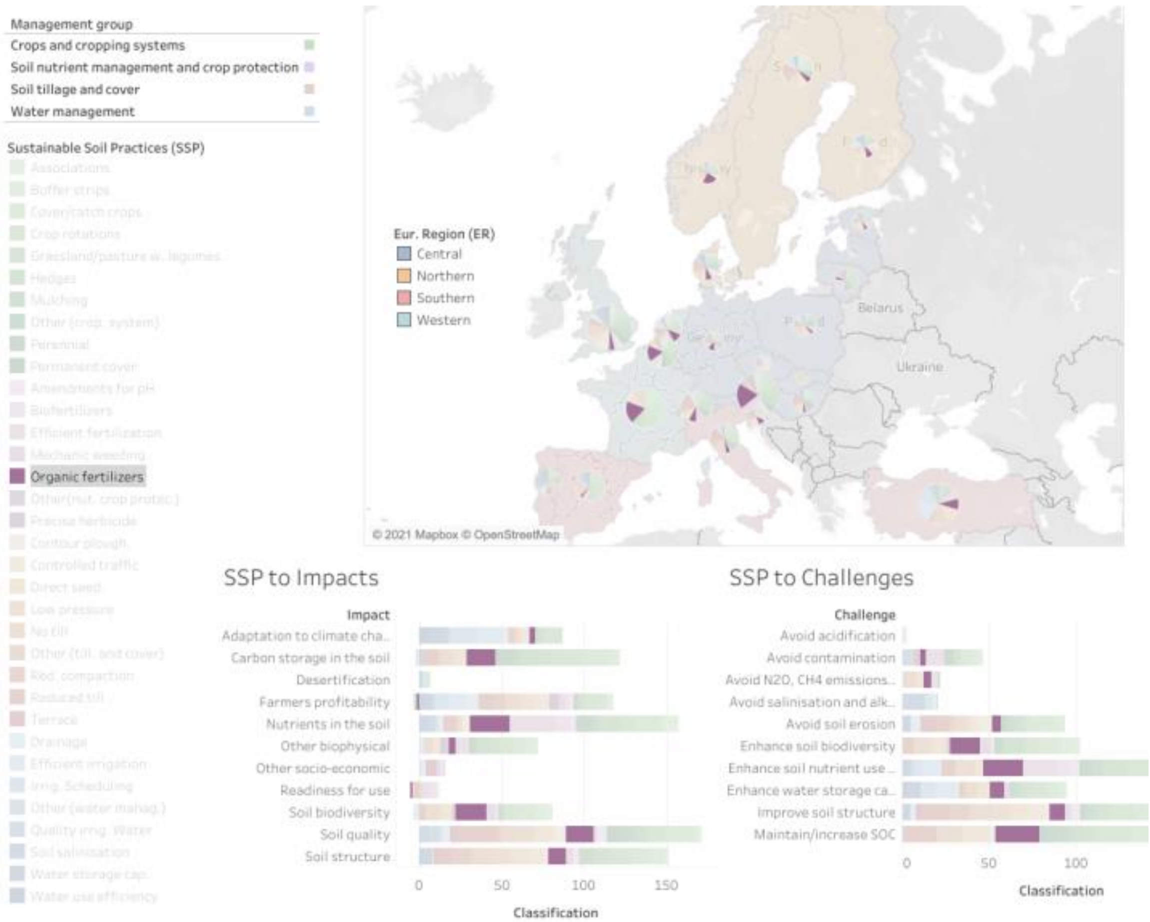

Figure 3. Example of a specific analysis with the interactive toll developed within this project: countries reporting on the SSP "Organic fertilizers" and the associated impacts and challenges.

Table 2 shows a summary of the results relative to the different number of SSP, impacts and challenges reported by the participating countries, within each of the four management groups. All countries reported a substantial number of different SSP, impacts, and challenges, within each management group. The total shows that “Crop and cropping systems” is the most represented category, followed by “Soil tillage and cover”, “Nutrient management and plant protection”, and “Water management”. There were less SSP associated with water management and is the only management group with no reported SSP from three countries and no reported challenges from eleven countries.

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Table 2. Summary with total different SSP[1], impacts, and challenges reported within each management group by country.

	Soil tillage and cover			Crops and cropping systems			Nutrient management and plant protection			Water management		
	SSP	Impacts	Challenges	SSP	Impacts	Challenges	SSP	Impacts	Challenges	SSP	Impacts	Challenges
Austria	3	6	4	7	5	6	6	8	7	3	7	2
Belgium	3	4	4	8	7	6	5	8	8	1	2	2
Czechia	3	2	2	1	1	1	2	2	2	1	1	0
Denmark	5	6	4	7	6	6	4	4	4	4	4	2
Estonia	3	3	3	3	2	3	3	1	2	2	2	2
Finland	5	4	2	4	5	5	4	6	3	5	5	3
France	2	3	3	4	4	5	1	3	4	0	0	0
Germany	3	4	3	3	3	4	3	4	3	1	1	0
Hungary	6	4	3	7	4	3	3	2	2	3	3	0
Italy	4	6	6	6	8	6	3	3	0	4	1	1
Latvia	2	2	2	1	0	2	1	1	0	0	0	0
Lithuania	4	6	3	5	6	6	4	5	3	1	2	2
Netherlan.	4	7	6	4	6	4	6	7	4	4	3	2
Norway	5	3	3	4	5	5	2	4	5	3	3	1
Poland	5	3	5	4	4	3	4	3	2	4	3	0
Portugal	2	7	5	4	3	5	2	2	1	5	5	5
Slovakia	1	3	1	1	2	0	1	2	1	0	0	0
Slovenia	2	3	3	2	2	3	3	3	2	1	1	0
Spain	1	3	3	3	7	6	4	4	4	6	4	2
Sweden	5	3	1	4	3	3	1	1	1	3	2	0
Switzer.	2	2	2	4	5	4	3	4	5	2	2	0
Turkey	3	3	3	2	4	4	2	2	3	5	4	5
UK	6	7	5	8	7	7	4	7	4	3	6	5
Total	**79**	**94**	**76**	**96**	**99**	**97**	**71**	**86**	**70**	**61**	**61**	**34**

[1]When the same SSP is reported for more than one ENZ inside a country, the SSP is accounted only once per country.

4.1. Analysis of the sustainable soil management practices (SSP)

This section gives an overview of the reported SSP, organized by the four management groups and at the overall level (Figures 4 and 5), by Environmental Zone (Figure 6), and by European Region (Figure 7). Figure 4 shows the overall representativeness of the four management groups, considering the reported SSP. The group "Crop and cropping systems" represented 31% of the reported SSP, followed by 26% in "Soil tillage and cover", 23% in "Nutrient management, and 20% in "Water management". This ranking of the management groups, already observed in Table 2, might be partly explained by the level of specificity of the SSP included in each group, as the last group "Water management" includes SSP related to active water management, which are not applied to all agricultural systems. However, this ranking also points out to the level of knowledge about SSP in the different groups, indicating a substantial difference between groups such as “Crop and cropping systems” and “Nutrient and crop protection”, which both include generally applied SSP.

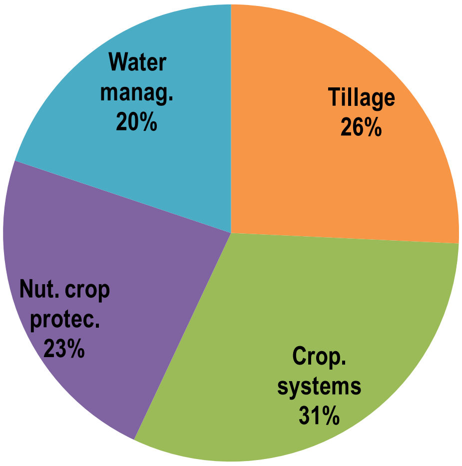

Figure 4. Overall representativeness of the four management groups.

Figure 5 shows the reported SSP accounted once per country (*i.e.* if the SSP was reported for different ENZ in the same country, it is only accounted once), in order to avoid biases resulting from the different number of ENZ in each country. Figure 5 shows that there is a clear ranking in the SSP reported by all collaborating countries, which indicates that there is larger overall knowledge over some SSP compared to others, with generally two SSP in each management group dominating the number of reported practices:

- ➔ The two most reported SSP in the group “Soil tillage and cover” (Figure 5a), were “Reduced tillage” and “No till”. In “Other”, the practice “Temporary ditches” was reported once.
- ➔ The two most reported SSP in “Crop and cropping systems” (Figure 5b), were “Cover/catch crops” and “Crop rotations”. In “Other” were identified practices related to agro-forestry, short rotation coppice, extensive systems, and management of former peatland.
- ➔ In the group “Nutrients management and crop protection” (Figure 5c), the two most reported SSP were “Organic fertilizers” (this was also the most reported practice overall) and “Efficient fertilization”. In “Other”, the protection against nematodes was reported.
- ➔ In the group, “Water management” (Figure 5d), the most reported SSP were “Drainage” and “Improve water storage capacity”. In “Other”, practices related with the monitoring of water quality and the construction of wetlands were reported.

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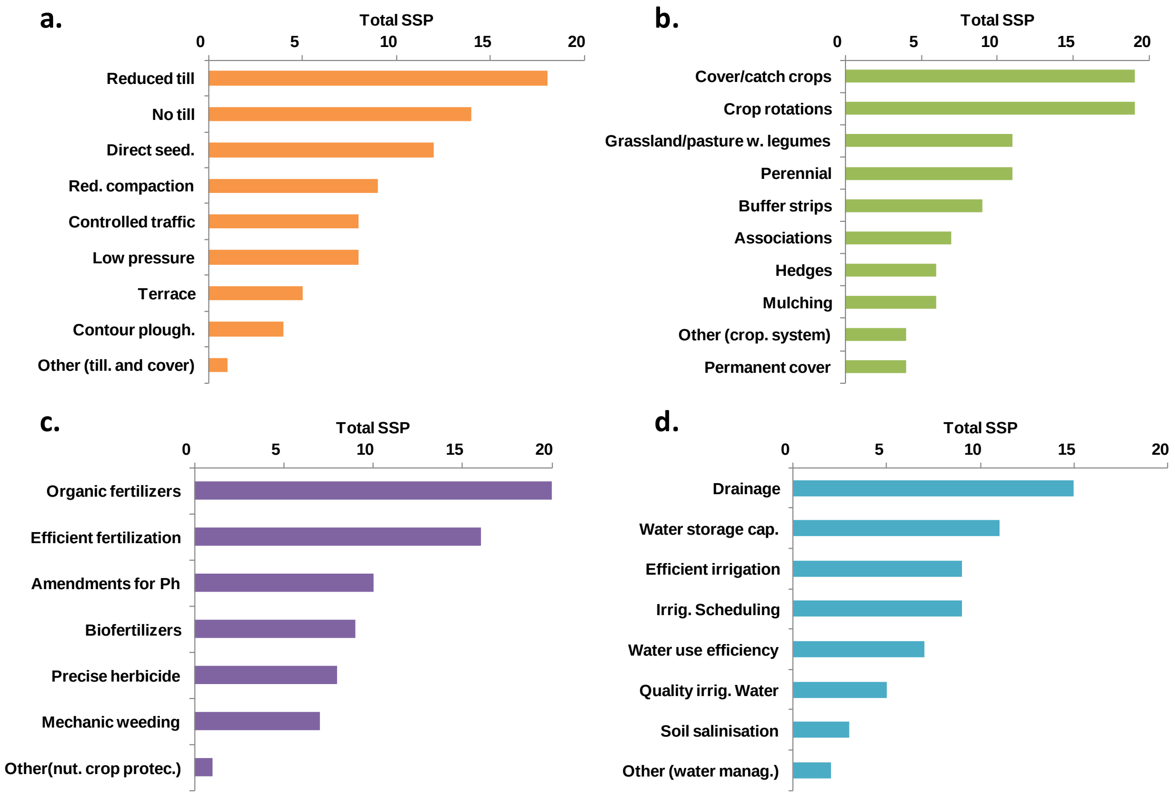

Figure 5. Overall reported SSP (accounted once per country), in the four management groups: a. Soil tillage and cover; b. Crop and cropping system; c. Nutrient management and crop protection; d. Water management.

Figure 6 shows the SSP reported for each ENZ, in percentage of their relative frequency. The figure shows that:

➔ All ENZ[4] include SSP in the four management groups, although there is substantial variation in their relative representativeness among different ENZ;

➔ Considering the group "Soil tillage and cover", the SSP "No till" and "Direct seeding" were identified in all ENZ except for "No till" in ALS. This indicates that these practices are applied across Europe and/or investigated extensively in scientific studies. However, countries stated that "No till" is applied on relatively small areas of arable land, as shown in Figure 3. "Reduced tillage" was not reported in LUS, MDM, MDN, and MDS, even though the practice appears to be used in these zones (see Table 3), but was likely reported under "No till".

"Controlled farming traffic" and "Low pressure" were not reported in LUS, MDM, MDN, and MDS, but are present in all other ENZ.

➔ The group "Crop and cropping systems" was the dominant group in several ENZ. The SSP "Crop rotations" was reported in all ENZ. "Cover/catch crops", "Grassland/pasture with legumes" and "Perennial crops" were reported in almost all ENZ. The broad application of these practices can be

[4] ALN was omitted from the figure has it had no reported practices.

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related (as also indicated by some of the research teams) to their inclusion in the Common Agricultural Policy (CAP) as conditions for receiving support.

- Considering the group “Nutrient management and crop protection”, the SSP “Organic fertilizers” was reported in all ENZ.

  “Efficient fertilization” was reported by almost all ENZ. In many countries this practice refers to an implemented system at national/regional level that supports farms with fertilization requirements. It is sometimes accompanied by a soil monitoring scheme.

  “Biofertilizers” was reported in almost all ENZ, evidencing the interest in this more innovative practice. The practice is often described as an innovative practice with potential, but which still needs further research in order to be able to fully understand the benefits.

- In the “Water management” group the most reported SSP among ENZ were “Drainage” and “Efficient irrigation”. Generally, drainage systems in ENZ such as ATN and CON referred to systems originally designed mainly to reduce the water content in soils from strong rainfall, groundwater or even wetlands, while in MDS these practices refers mostly to systems for draining the excess of rain and irrigation water.

Figure 7 shows the SSP reported in each ER, in percentage of their relative frequency. The figure shows that:

- All the ER included SSP in the four management groups, but it is possible to identify relatively different levels of knowledge between ER: in Northern Europe, the main group was “Soil tillage and cover”, in Central Europe, the main group was “Crop and cropping systems”, in Western Europe it was “Crop and Cropping systems”, and in Southern Region, the main group was “Water management”.
- Considering the group “Soil tillage and cover”, “No till” was more representative in Southern Europe, while in other regions where “Reduced tillage” was more reported. When all soil cultivation practices are combined (No till, Direct seeding, Reduced tillage), their relative occurrence was lowest in Northern Europe. “Contour ploughing” was reported by few countries and only in Western and Central Europe. All regions reported practices to reduce soil compaction. “Controlled traffic” and “Low pressure” were reported in all regions except Southern Europe. “Terraces” was identified in Southern and Central Europe, which could be explained by the more mountainous conditions in these regions.
- All the SSP in the group “Crop and cropping systems” were reported for all ER. This can be due to the effect support measures defined under the CAP.
- All SSP in “Nutrient management practices” were reported for all ER, except “Mechanical weeding” in Southern Europe, “Biofertilizers” in Western Europe, and “Precision herbicide” in Northern Europe.
- Considering the group “Water management”, the SSP “Efficient irrigation”, “Irrigation Scheduling”, “Drainage”, and “Improve water storage capacity” were reported in all ER, evidencing the

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importance and knowledge about irrigation and drainage practices over all European regions. “Monitoring of soil salinization” was reported only in Southern and Western Europe, indicating the more regional relevance of soil salinisation.

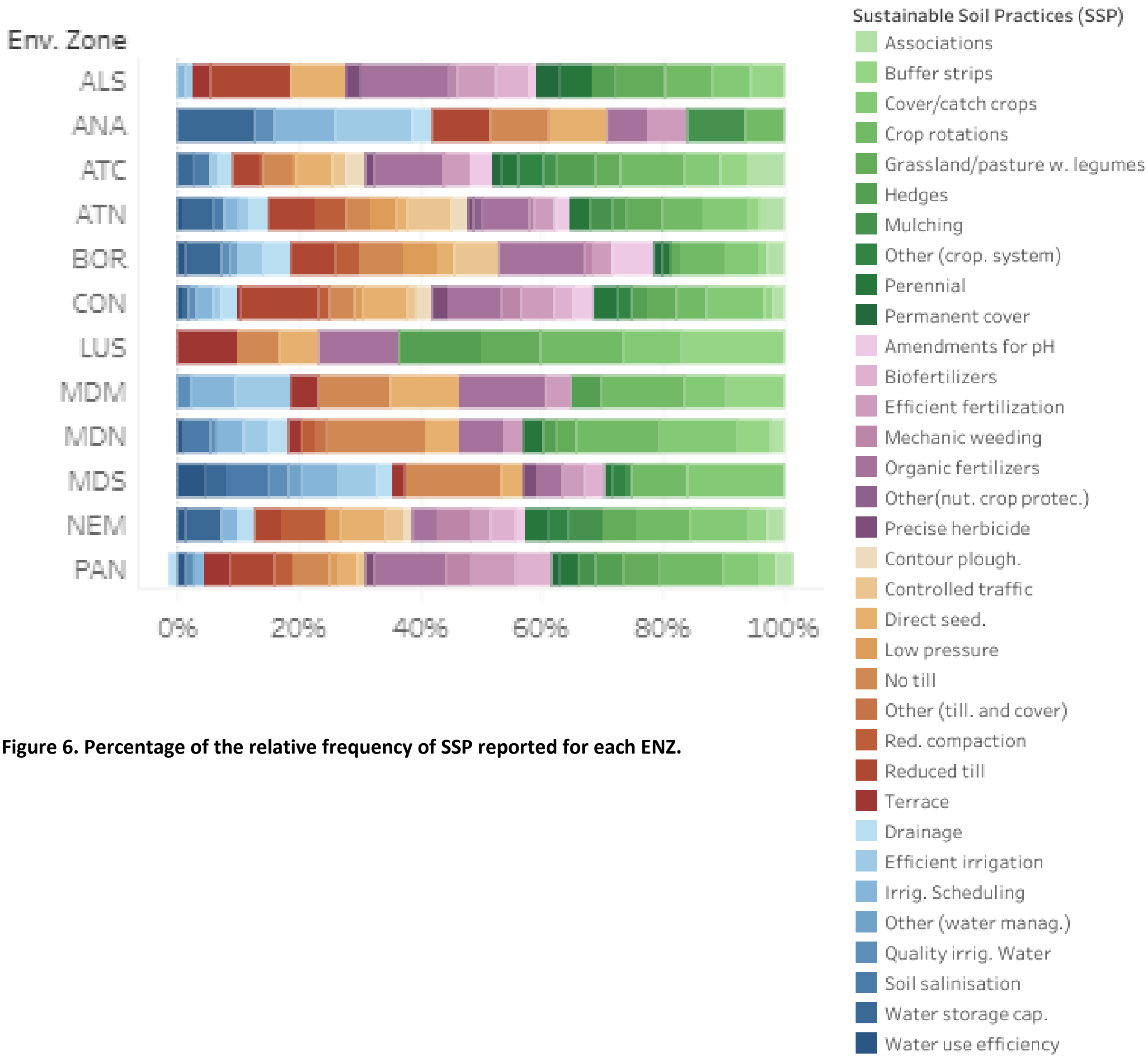

Figure 6. Percentage of the relative frequency of SSP reported for each ENZ.

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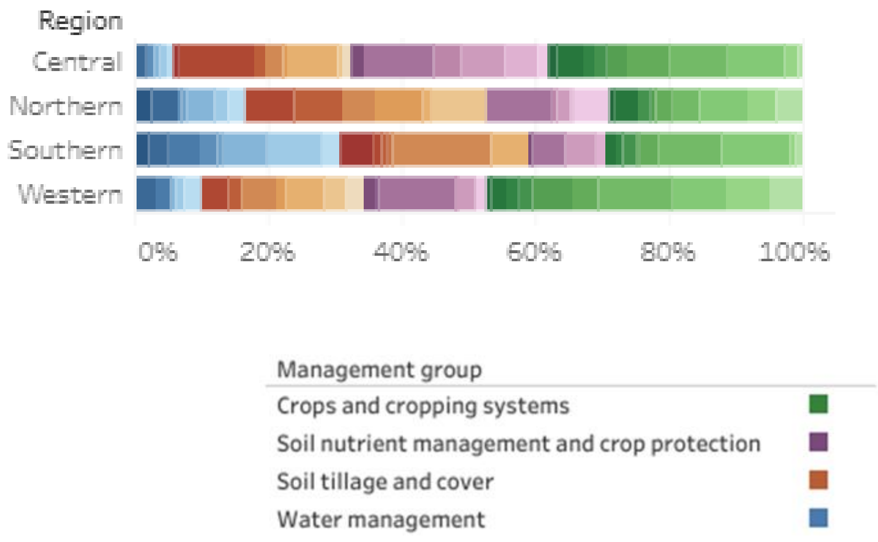

Figure 7. Percentage of the relative frequency of SSP reported for each ER.

Table 3 summarizes all the quantitative information provided in the questionnaires by collaborating countries relative to the level of deployment of the SSP. The information received concerning the area of implementation was of different forms and included several parameters depending on the country.

Table 3. Summary of quantitative information regarding the level of deployment of the reported SSP.

Country	**Conservative soil tillage practices**
Austria	No-till in 2% of cropland and non-inversion in 30%
Denmark	2% no-till 18% non-inversion 16% reduced tillage
Slovenia	2% no-till 14% non-inversion/reduced tillage
Italy	4.7% no-till
Lithuania	10% all conservation tillage
Norway	Minimum 1.2 % and maximum 17 % in 2000-2017.
Slovakia	Potential estimated of 25% (no statistics for actual area)
Spain	43% reduced till in woody crops 65% no till and reduced till in vineyards 52% no till and reduced till in olive orchards 21% no till and reduced till in cereal crops and crop rotations
Sweden	25% reduced tillage in Southern Sweden (NEM and CON) ~1% no-till
UK	45% of farms use some form of conservation tillage
Country	**Cropping practices.**
Austria	~20% for cover/catch crops
Slovenia	~66% Permanent grassland
Sweden	~45% of annual crops with grass buffer strips

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Portugal	~31% of area subject to crop diversification under CAP rules, “biodiverse pastures" occupying an area >500 000 ha in 2010, and agroforestry systems in 8.8% (781 517 ha of the total area in 2010)
Country	**Nutrient management**
Austria	25% area (21% farms) in organic farming
Germany	About 60% of all arable land is fertilised organically because specialisation and the spatial separation of livestock farms and market fruit farms continues to progress. In regions dominated by market fruits, such as eastern Germany, only about 40% of all arable land is fertilised organically. Other organic fertilizers are only available in limited quantities. Only 1 to 2% of arable land can be supplied with compost.
Norway	Approximately 34% of N and 58 % of P applied to agricultural soils originates from manure. The total fertilizer usage decreased by 35% in 2018/2019 resulting from a significant price increase the same year.
Portugal	7% area in organic farming
Country	**Water management**
Austria	1.5-2% area is irrigated
Czech Republic	The drainage area covers as much as a third of currently or formerly agriculturally managed land, measured as a surface area of ~1.1 mil. Ha
Denmark	11% of the cultivated area was irrigated in 2018, mainly located in the western part of the country.
Slovenia	1.7% of the cultivated area was irrigated in 2018 (3200 ha), located in the eastern part of the country and also in the western part.
Spain	The largest irrigated area in Europe with 3.828.747 ha. Drip irrigation is applied in 53%; surface irrigation in 24%; sprinkler irrigation in 15% and other forms or pressurized irrigation in 8%. All types of crops are irrigated, from field crops mainly irrigated by central pivots to intensive horticulture mainly irrigated with drip localized systems. Irrigation is one the main drivers of N leaching and this is in part because irrigation scheduling decision-making is still often and fundamentally tied to the local grower’s experience. When water availability fails to meet a crop’s requirements, irrigation can be scheduled by partial root zone drying strategies where only a limited volume of the root zone is wetted by the irrigation system. Alternatively, irrigation can be reduced during the entire crop growing period (deficit irrigation) or only in those phonological stages in which yield is relatively less sensitive to soil water deficits (regulated deficit irrigation).
Sweden	About 30 % of the agriculturally used land is naturally drained, while 50% are drained artificially with a subsurface drainage system. Irrigation is limited to Southern Sweden and occupies an area of less than 100 000 ha.
Portugal	About 13% of the agricultural area is irrigated (~462 000 ha) (data from 2014)

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4.2. Analysis of the impacts of SSP

The participating teams identified up to three impacts, from the list of predefined impacts, for each of the reported SSP, as described in section 3.1. In the description of the impacts, they could be described as positive, negative, or neutral. The research teams were also asked to report these impacts quantitatively whenever possible. All the quantified impacts that were reported for main SSP in each management group were summarized in Table 4 in Annex I. In this manner, Table 4 represents a comprehensive overview of the quantitative impacts provided by each country. It should be noted that:

a) In this table are only presented the impacts that were reported by the countries in the questionnaire. Some countries might have referred to impacts, but did not provide quantitative evidences in the appropriated fields in the questionnaire.

b) The summary in Table 4 can be further completed by analysing the references provided by the countries in the questionnaires.

The overall impacts reported by all contributing countries and the associated SSP are presented in Figure 8. Considering the overall relevance of the reported impacts, Figure 8 shows that:

- ➔ The three most reported impacts were “Soil quality”, “Nutrients in the soil”, and “Soil structure”. These impacts are transversal to several SSP and pedo-climatic conditions across ER and are of major importance for agricultural soils in general.
- ➔ The impacts “Desertification”, “Readiness for use”, and “Other socio-economic” were rarely reported.
- ➔ Negative impacts were reported for “C storage in the soil” (SSP of “Mechanical weeding” and “drainage”), “Farmers’ profitability” (SSP of “Hedges”, “Permanent cover”, and “Organic fertilizers”), “Soil biodiversity” (SSP of “Drainage”), and “Readiness for use” (SSP of “Organic fertilizers”, “Direct seeding“, and “Reduced till”).
- ➔ Neutral impacts in “C storage in the soil” were also reported in 4 studies related to SSP of “No till”, “Reduced till”, and “Direct seeding” (more details in Table 4 of Annex I).
- ➔ In “Other biophysical” are identified positive impacts on total ecosystem biodiversity and reduction of contamination to surface and ground water.

Considering the relation between SSP and the six most reported impacts, Figure 8 shows that:

- ➔ The main SSP addressing “Soil quality” were “Reduced tillage”, “No till”, “Organic fertilizers”, and “Cover/catch crops”. The majority of SSP associated to this impact were in the groups of “Soil tillage and cover” and “Crops and cropping system”;
- ➔ The main SSP contributing to the impact “Nutrients in the soil”, were “Efficient fertilization”, “Organic fertilizers”, and “Cover/catch crops”. The majority of SSP associated to this impact were in the group of “Nutrient management and crop protection” and “Crops and cropping system”;

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- ➔ The main SSP contributing to “Soil structure” were “No till”, “Direct seeding”, and “Crop rotations”. The majority of associated SSP were in the categories of “Soil tillage and cover” and “Crops and cropping system”;
- ➔ The impact on “Carbon storage in the soil” is associated with a majority of SSP in the group of “Crops and cropping system” and “Soil tillage and cover”;
- ➔ “Farmer’s profitability” impact is associated with a majority of SSP in the categories of “Soil tillage and cover” and “Water management”;
- ➔ “Adaptation to climate change” is associated with a majority of SSP in the group of “water management”. Such SSPs are considered by contributing partners as a need when adapting crop production to climate change.

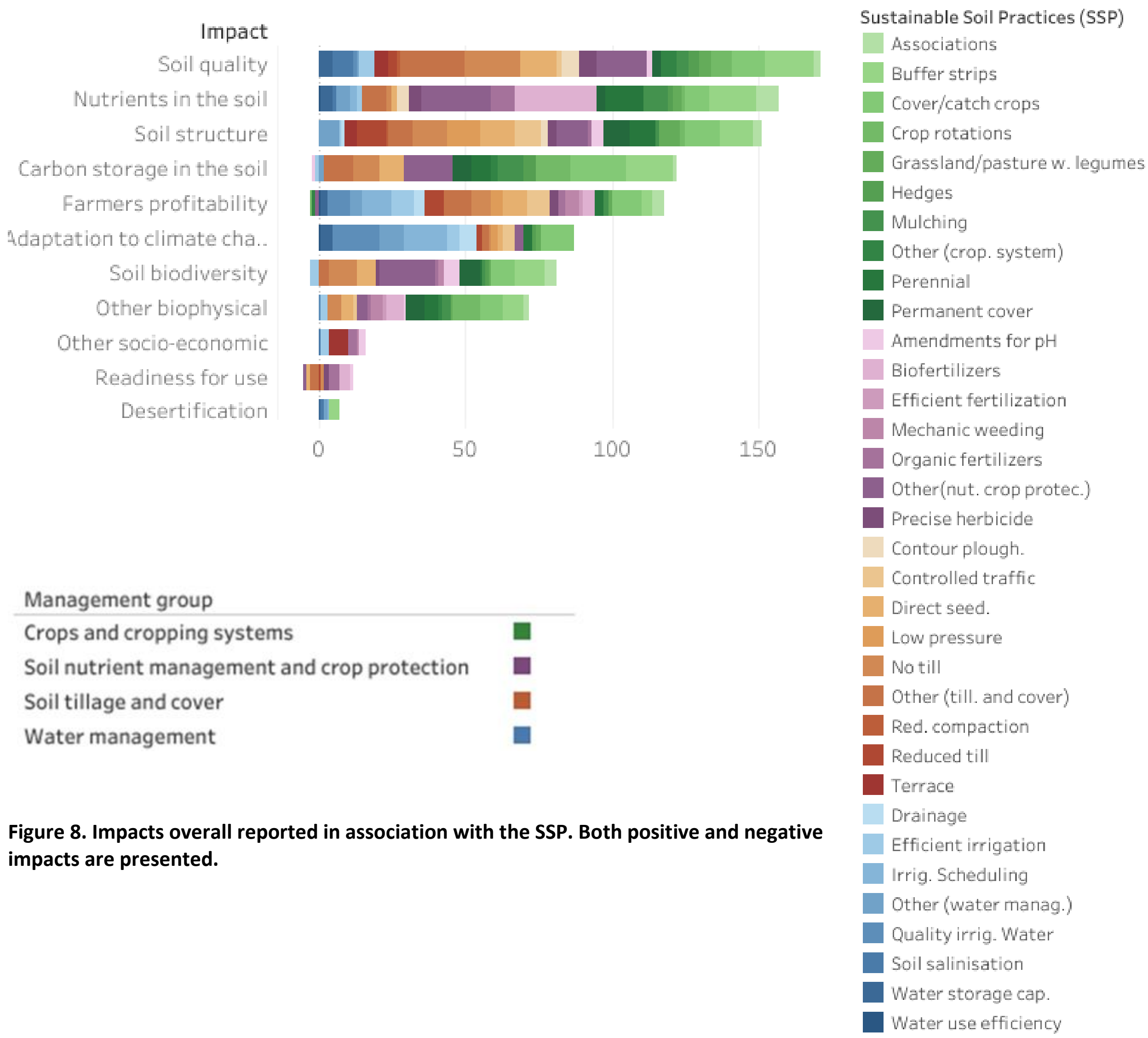

Figure 8. Impacts overall reported in association with the SSP. Both positive and negative impacts are presented.

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Figures 9 and 10 show the percentage of impacts reported for each ENZ and ER, respectively. Because ENZ and ER consist of different number of countries, these figures present the percentage of total counts for each impact. Figure 9 shows that:

➔ Most impacts are reported in all ENZ, which indicates some overall level of knowledge over those impacts. Clear trends regarding reported knowledge among different ENZ are not evident, except for "Desertification" which is the more asymmetrically reported impact, occurring only in MDS and PAN. "Readiness for use" impact has few reports in only half of the ENZ.

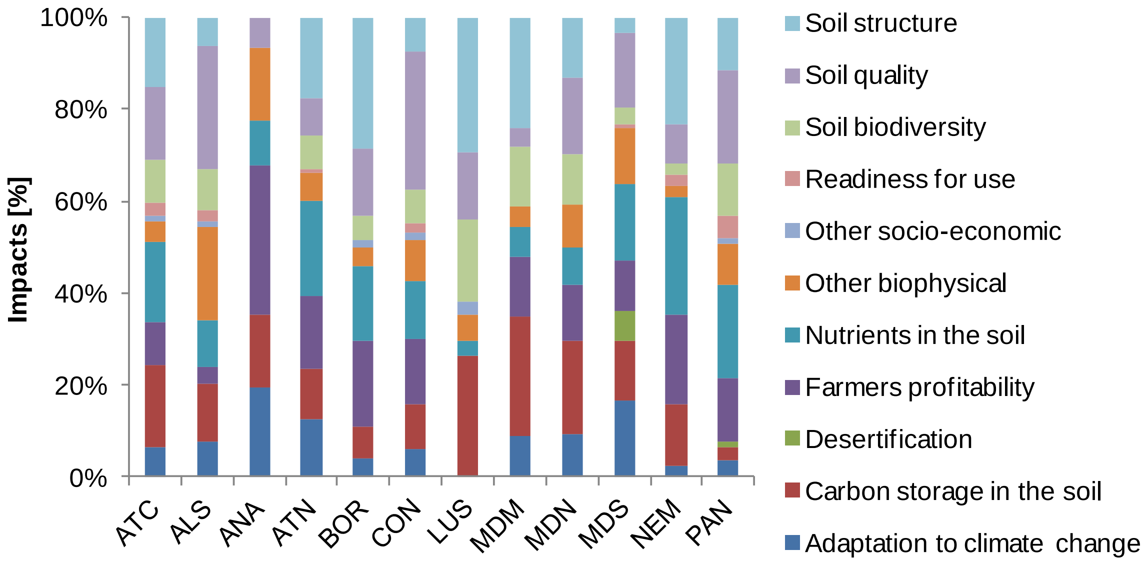

Figure 9. Percentage of impacts reported in each ENZ. The percentage of total counts allows analysing the relative importance of the impacts among ENZ.

The analysis by ER presented in Figure 10 shows that:

➔ Most impacts are reported for all ER. The exceptions are "Desertification" which is only reported in Southern Europe and very marginally in Central Europe, and "Readiness for use", which is not reported in Northern and Southern Europe.

➔ "C storage in the soil" was relatively less reported in Northern Europe than in other ER, which might result from a less relevance of this issue in the soils of Northern Europe when compared to the other ER.

➔ "Adaptation to climate change" was relatively more reported in Southern Europe than in other ER. This result might indicate a relatively higher knowledge towards this impact in this ER, which can be explained by the climate conditions in this ER, compared to the others.

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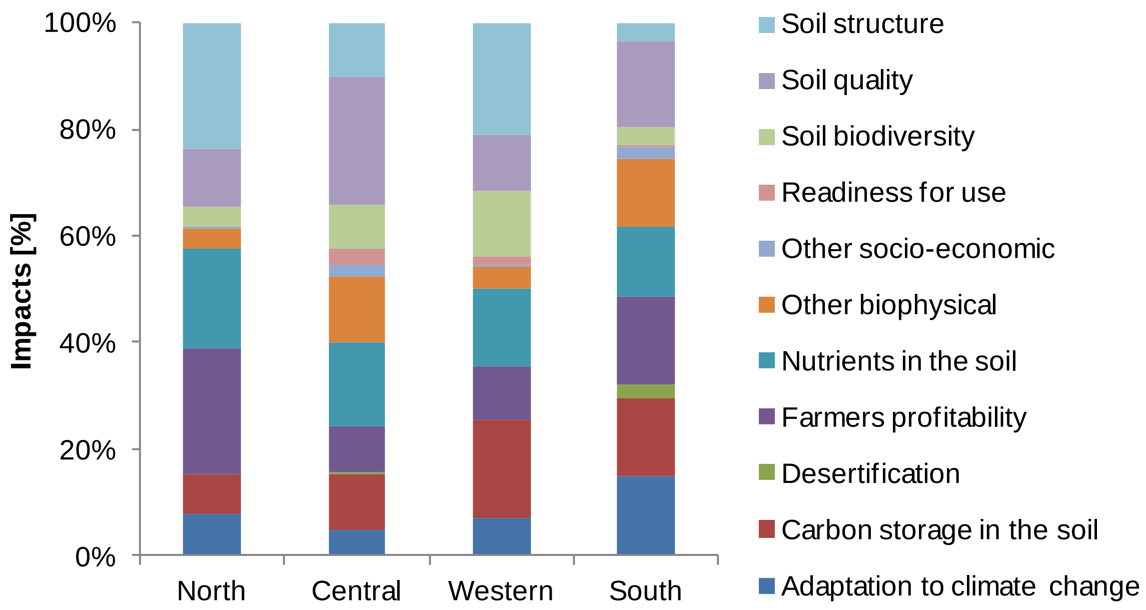

Figure 10. Percentage of impacts reported in each ER. The percentage of total counts allows analysing the relative importance of the impacts among ER.

4.3. Analysis of the soil challenges addressed by the SSP

The contributing countries were also asked to associate one of the EJP SOIL soil challenges with the reported SSP. Figure 11 shows the challenges associated with the SSP with positive impacts (SSP with only negative impacts were not associated to challenges) for the overall contributing countries:

- ➔ The three most reported challenges were “Enhance nutrient use efficiency”, “Maintain/increase SOC”, and “Improve soil structure”. The EJP SOIL challenges “Avoid acidification”, “Avoid salinisation/alkalinisation”, “Avoid N_2O and CH_4 emissions from soils” were rarely reported. The challenge “Avoid peat degradation” and “Avoid soil sealing” were not related to any SSP.
  - ➔ The group “Crop and cropping systems” represents the majority of SSP contributing to the challenges “Enhance nutrient use efficiency”, “Maintain/increase SOC”, and “Enhance soil biodiversity”. The group “Soil tillage and cover” represents the majority of SSP contributing to the challenges “Improve soil structure” and “Avoid soil erosion”.
  - ➔ The group “Soil nutrient management and crop protection” is more represented by SSP contributing to the challenge “Enhance nutrient use efficiency” as expected, and also to “Enhance soil biodiversity”.
  - ➔ The group “Water management” represents the majority of SSP contributing to the challenges “Enhance water storage capacity” and “Avoid salinization and alkalinisation”.

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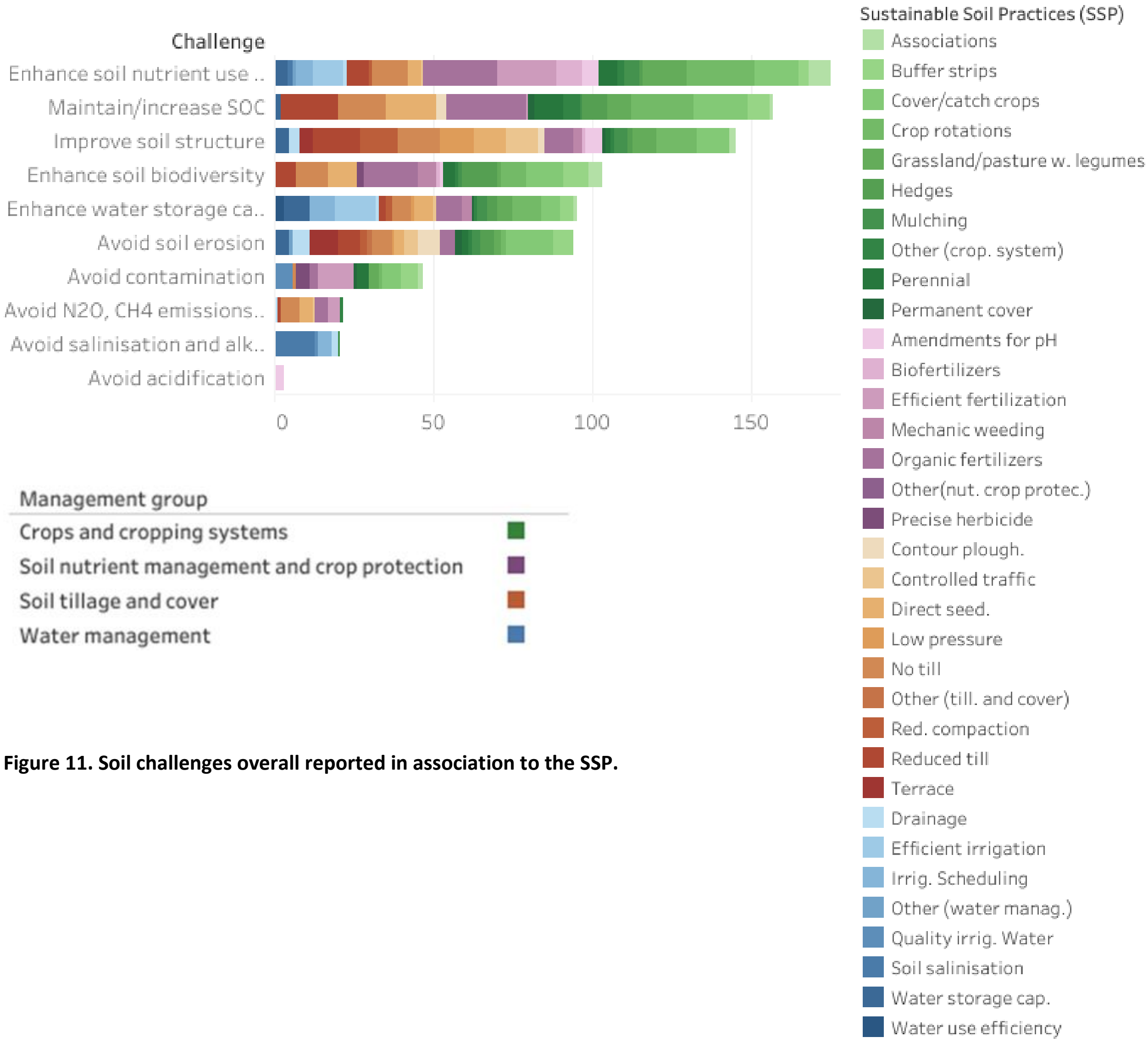

Figure 11. Soil challenges overall reported in association to the SSP.

Figures 12 and 13 show the soil challenges and the associated SSP, by ENZ and ER, respectively. Figure 12 shows that:

➔ The challenges are reported in more or less similar proportions for almost all ENZ. Some exceptions are: BOR and NEM where the challenge "Improve soil structure" has higher percentage, BOR does not include the challenge "Enhance water storage capacity", LUS does not include "Avoid contamination", and "Avoid N2O and CH4 emissions from soils" is not reported for ANA, BOR, LUS, PAN.

➔ The challenges less represented in all ENZ are "Avoid acidification", "Avoid salinisation/alkalinisation", and "Avoid N2O and CH4 emissions from soils". The challenge "Avoid acidification" was only considered in ATC and CON, while "Avoid salinisation and alkalinisation" was not reported in half of the ENZ (ALS, BOR, CON, LUS, NEM e PAN).

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Figure 13 shows that:

- ➔ Although most challenges are reported in all ER, there is some variability among ER for the most reported challenges, for instance: "Soil structure" has larger expression in Northern Europe than in other ER, with minimum reports in Southern Europe, "Maintain increase SOC" is more reported in Central Europe, and "Enhance soil biodiversity" is more reported in Western Europe
- ➔ The challenge "Avoid salinisation and alkalinisation" is only reported in Western and Southern Europe, which can result from regional concerns associated with irrigation management practices and climate conditions.
- ➔ "Avoid acidification" is only reported in Central and Western Europe which points out to concerns over acidification effects in these regions.
- ➔ "Avoid N2O and CH4 emissions from soils" is not reported in Northern Europe.

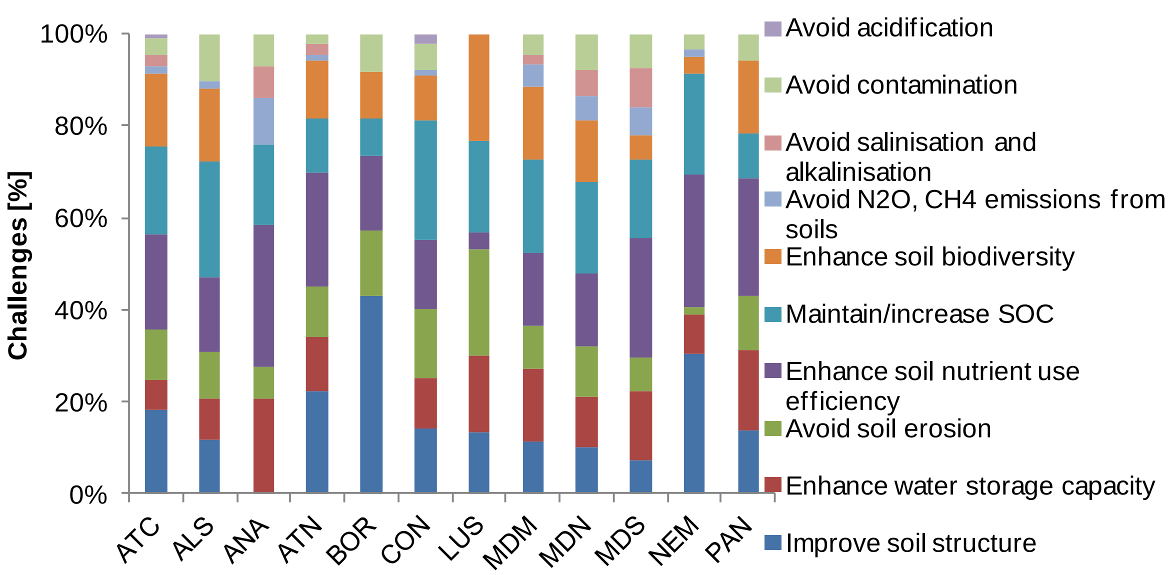

Figure 12. Percentage of Soil challenges associated to SSP reported for each ENZ. The percentage of total reports allows analysing the relative importance of the soil challenges among ENZ.

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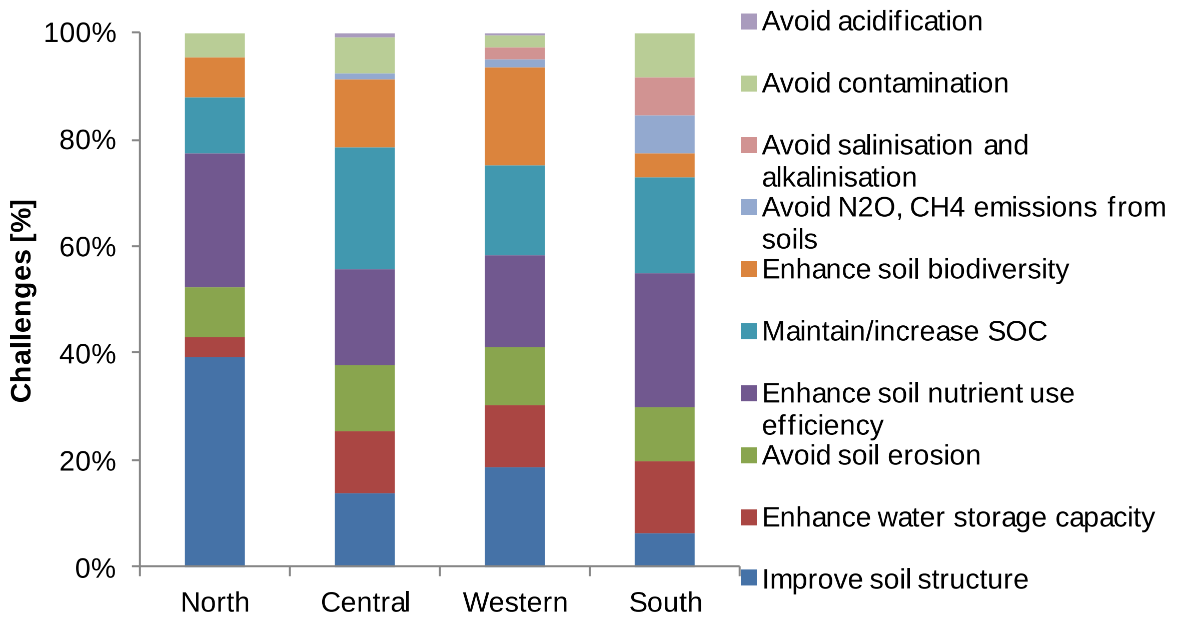

Figure 13. The percentage of Soil challenges associated to SSP reported for each ER. The percentage of total reports allows analysing the relative importance of the challenges among ER.

5. Limitations of the synthesis

The synthesis constituted an effort of comprehensive and harmonized compilation of information among EJP SOIL participating countries and provided original results for understanding the level of knowledge about the impacts of sustainable soil management practices. Even though, it is important to point out the limitations of the analysis by enumerating the following points:

- The area of knowledge that comprises all the sustainable soil management practices is rather broad and quite challenging to tackle within the resources of this task.
- The detail level of the information provided by the contributing countries was not always uniform, despite the questionnaire sent. Some participants provided extensive reporting, while others provided incomplete answers. Only one EJP SOIL participating country (Ireland) did not participate in the synthesis.
- Despite the efforts in organizing the questionnaire, the participating teams adopted different criteria for categorizing the soil management practices and impacts. This is evident in answers regarding practices categorized as "No till" and "Direct seeding". This limitation was partly overcome by developing rules for harmonization of the data categorization (see section 3.3).
- Some of the participating countries found the level of detail of the questionnaire and the time necessary to answer above the time provided for the task (1PM/country). This resulted in some gaps in the reporting.
- This synthesis report provides an overview of the collected information and cannot always cover the level of detail of some of this information.

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6. Conclusions

6.1. General conclusions

This synthesis presents the information assessed by the research teams of 23 EJP SOIL participating countries about the knowledge on the impacts of sustainable soil management practices (SSP). Inputs received by EJP SOIL partners were generally more detailed on the SSP used in each country rather than on the impacts resulting from the SSP. The results were organized by the reported SSP, their respective impacts, and associated soil challenges at three levels: overall results for contributing countries, by ENZ and by ER.

General conclusions focusing of SSP

- Considering the SSP by themselves, it was possible to identify larger overall knowledge over some SSP compared to others. In each management group there were generally two SSP that were dominant.
- “Crop and cropping systems” was the management group with most reported SSP (31%) evidencing the larger body of knowledge about practices in this group. “Water management” was the less reported (20% of SSP), which might reflect the fact that it includes more specific SSP which are not applied to all agricultural systems.
- The geographic analysis of the results was generally most suitable for drawing conclusions due to an improved level of aggregation of the information, when compared to the analysis by ENZ.
- All the ER included SSP in the four management groups, but it is possible to identify relatively different levels of knowledge between ER: in Northern Europe, the main group was “Soil tillage and cover”, in Central and Western Europe, the main group was “Crop and cropping systems”, and in Southern Region, the main group was “Water management”. This ranking is likely to reflect the relative importance and knowledge available on the SSP of the management groups and also on the agricultural soils’ needs and crop production demands in the different ER.
- There was a widespread (over most ENZ and ER) and large knowledge reported in relation to SSP in “Crop and cropping systems” such as “Crop rotations”, “Cover/catch crops”, “Grassland/pasture with legumes” and “Perennial crops”, which can be related (as also indicated by some of the research teams) to their inclusion in the Common Agricultural Policy as conditions for receiving support.
- Overall, the most reported SSP was “Organic Fertilizer”. Several positive impacts related to this SSP were reported (“Nutrients in the soil”, ”C storage in the soil”, “Soil biodiversity”, “Soil quality”, ”Soil structure”, and “Adaptation to Climate change”). It had reported negative impacts (once each) “Readiness for use” and “Farmers profitability”. The three main challenges associated were “Maintain/increase SOC”, “Soil nutrient use”, and “Enhance soil biodiversity”.

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- Also in the group "Nutrient management and plant protection", "Efficient fertilization" revealed widespread and good level of knowledge. Many countries refer to an implemented system at national/regional level that supports farms with fertilization requirements, sometimes accompanied by a soil monitoring scheme.
- In the group "Water management", SSP are reported in all ER. Although it could be expected that irrigation practices would be more reported in Southern Europe due to the limitations in the availability of rainwater for crop production, these SSP are reported in all ER. Countries such as NL and UK report an increased interest in irrigation in the face of climate change conditions and report quantitative results of studies on its economic viability. On the other hand, "Monitoring of soil salinization" was reported only in Southern and Western Europe, indicating the more regional relevance of soil salinisation.

General conclusions focusing on the impacts:

- The most overall reported impact was "Soil quality", which can partly be explained by the broad applicability of this category, because it is associated to a very large number of SSP in all management groups and with all soil challenges. This impact was followed by "Nutrients in the soil", and "Soil Structure", which were reported for all ENZ and ER. This result indicates a widespread and large knowledge about SSP contributing to these impacts.
- "Desertification" was the less reported impact. It was reported marginally in Southern Europe and once in Central Europe, associated with SSP in the "Water management" and "Crop and cropping systems" groups, and the challenges "Avoid soil erosion" and "Enhance soil water storage". This low level of reported knowledge could be explained by the fact that desertification is a cross-cutting issue resulting from a set of degradation processes, that was possibly associated with other impacts and soil challenges, and it may have been considered individually in them. Anyway, the results indicate that few studies are conducted considering the integration of the different degradation processes involved in desertification in several European contexts. This is somehow less expected since desertification is of serious and in some cases irreversible consequences (e.g., in PT 63% of the land is susceptible to desertification[5]) in several ERs and mainly in Southern Europe and can be expected to be exacerbated by climate change.
- The impacts "Readiness for use" and "Other socioeconomic" were also rarely reported, which points out to a lower level of knowledge over the socioeconomic impacts of SSP, with the exception of the impact "Farmers profitability". Also, most of these impacts lacked quantitative evidence.

[5] Lúcio Pires do Rosário, 2020. Desertificação em Portugal. Breve resenha. Webinar Dia da Desertificação e Seca 2020. "Food. Feed. Fibre. Consumo e Produção Sustentável". CNCCD – Comissão Nacional de Coordenação de Combate à Desertificação, Lisbon, Portugal.

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- Knowledge about the impact "C storage in the soil" was less reported in Northern Europe than in other ER, which points out to the lower relevance of this issue in the soils of this region when compared to the soils of Western and Southern Europe with less OM content.
- "Adaptation to climate change" was relatively more reported in Southern Europe than in other ERs. This result might indicate a relatively higher knowledge and awareness towards this impact in this ER, which can be explained by the limiting climate conditions for agricultural production in this ER that requires the use of irrigation practices, compared to the others.

General conclusions focusing on the challenges:

- The three most reported challenges were "Enhance nutrient use efficiency", "Maintain/increase SOC", and "Improve soil structure". These challenges were reported for all environmental zones and European regions with some variability. It points out to a high and widespread level of knowledge about SSP related to these challenges and reflects which are the main challenges of agricultural soils in Europe.
- The less reported EJP SOIL challenges were "Avoid acidification", "Avoid salinisation/alkalinisation", "Avoid N_2O and CH_4 emissions from soils". The lower reported knowledge on "Avoid acidification" (only reported for Central and Western Europe) and "Avoid salinisation and alkalinisation" (only reported in Western and Southern Europe) is likely to reflect the regional relevance of these challenges. On the other hand, "Avoid N_2O and CH_4 emissions from soils" would be expected to be of overall concern, although, there was a low amount of reported studies about emissions of N_2O and CH_4 from agricultural soils. Furthermore, the few studies show sometimes contradictory results, pointing out to the complexity and low level of knowledge on these processes. This can be due to the fact that it has not been a central question for farmers, agronomists, and researchers, as it has been outside the traditional goals of agriculture. The reduction of N_2O and CH_4 emissions from soils most likely needs more research and/or dissemination of known practices.

The report identifies the limitations of the synthesis, mainly related to different levels of detail in the reporting. The varying level of reporting of the SSP and their associated impacts and challenges can be related to varying levels of knowledge or awareness about these relations. A comprehensive summary of the reported quantitative impacts of SSP is provided in Annex I in Table 4.

6.2. Concluding remarks focused on specific roadmap topics

The roadmap for the second year of EJP SOIL will be developed using the findings of this and other reports resulting from WP2. This section compiles conclusions most directly related to three topics relevant in regards to the structure of the roadmap: sustainable agricultural production, adaptation to climate change, and mitigation of climate change.

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Sustainable agricultural production

From the several impacts related to sustainable agricultural production, this analysis will consider the impacts “Nutrients in the soil”, “C in the soil”, “Soil structure”, “Soil quality”, “Soil biodiversity”, and “Farmers’ profitability”.

- **“Nutrients in the soil”** was one of the two most reported impacts. It was reported for all ENZ and ER, with higher representation in NEM and PAN and with lower representation in South Europe.
- A majority of SSP (23 practices out of a total of 30) were related with the impact of nutrients in the soil. These SSP were mainly belonging to the group “Crop and cropping system” and with “Nutrient management and crop protection”.
- The most reported SSP with this impact were related to non-inversion/reduced tillage, to the promotion of soil cover (namely: “Crop rotations”, “Cover/catch crops”, “Grassland/pasture with legumes”). Furthermore, SSP that addressed the management of nutrients and fertilization requirements (namely: “Organic fertilizers”, “Efficient fertilisation”, “Biofertilizers”, and “Amendments for pH”), and SSP that addressed irrigation water management such as: “Drainage”, and “Efficient irrigation”.
- In several countries the impact on nutrients in the soil was related to SSP to reduce or prevent nutrients leaching and also nutrients losses by runoff with irrigation. For example, “Cover crops/catch crops” is referred to decrease or prevent nutrients leaching, yet there was low quantitative evidence was provided by partners. Also, the use of animal manure is referred in many countries but its application in soils can be limited by the common agricultural policy especially in the Vulnerable Zones to Nitrates.
- Many countries referred to the need of updated fertilisation guidelines to help in optimal nutrient supply to the soil. Also the need of analysing the soil nutrients more often and to have better knowledge about nutrition status of the soils is referred. To optimize nutrient flows and increase N efficiencies at farm level, “real” data is needed and also modelling tools can help. In several countries, fertiliser recommendations systems are implemented at national/regional level to support farmers and it is often accompanied by a soil monitoring scheme.
- The SSP “Biofertilizers” is mentioned in almost all ENZ which evidences the interest in using this technique. This practice is often identified as innovative and with potential to enhance nutrients availability to plants and increase crop yields, still is referred as lacking further research to understand its application in different pedo-climatic contexts. There is also the need of further studies to evaluate the economic costs associated with the adoption of this practice and the expected increased yields, to understand how it impacts farmers’ profitability.
- **“C in the soil”** was among the 4th most reported impacts. It was reported for all ENZ and ER, with higher representation in ATC, ALS, MDM, and MDS, and equally distributed in all ER with exception of Northern Europe with had less reports.

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- There were 15 SSP associated with the impact of "C in the soil", mainly belonging to the group of "Soil tillage and cover" and "Crop and cropping systems". The most reported SSP related to this impact were related to soil mobilization ("No till", "Reduced till", and "Direct seeding"), and to the promotion of soil cover (namely: "Crop rotations", "Cover/catch crops", and "Perennial crops").
- The effect of SSP in "C storage in the soil" is mainly reported for the top soil layers (until ~10 cm). In deeper soil layers, few inputs are reporting that no significant differences in "C storage in the soil" were found, or even that it decreases with depth. Information provided by participating countries indicates that further knowledge is needed on what extend do sustainable soil management practices impact "C storage in the soil".
- **"Soil structure"** was the 3rd most reported impact. It was reported for all ENZ with higher representation in BOR, NEM, and LUS. It was also reported for all ER, with higher representation in Northern Europe and less represented in Southern Europe.
- There were many SSP reported with the impact on soil structure (24 practices out of a total of 30), mainly belonging to the group of soil tillage and cover practices and crop and cropping systems. Within both groups, the practices with higher reports were related to "Low pressure", "Reduction of soil compaction", "Controlled traffic", and "Cover/catch crops". Also, practices to improve water storage capacity, infiltration and reduction of runoff was referred by participating countries as having impact on the soil structure.
- Impacts on soil structure were reported by increases in roots biomass, increases in the SOM and decreases in soil erosion. In Northern and Western European regions, the impacts on soil structure are addressed by using practices that control soil compaction, namely controlled farm traffic and the use of low pressure in tires. In Southern Europe, these practices were not reported. Some Northern and Western countries (DK, NO, FN, UK, BE, and FR) use a decision support tool that predicts the risk of soil compaction by farm machinery (Terranimo). The use of decision support tools in preventing soil compaction is of great usefulness for farmers, also farmers could benefit from incentives to overcome the short-term economic constraints on adapting their machinery.
- **"Soil quality"** was the most reported impact. It was reported for all ENZ and ER, with higher representation in CON and LUS and in Central Europe.
- Several SSP were associated with the impact on soil quality (25 practices out of a total of 30), mainly belonging to the group of soil tillage and cover practices and crop and cropping system. Within both groups, the practices with higher counts were related to non-inversion/reduced tillage, no tillage, and the use of cover/catch crops.
- Impacts on soil quality were diverse, as this impact comprises a wider variety of soil properties, characteristics and functions. Inputs from partners referred to reduced leaching of nutrients, pollution, and soil erosion, to increases in SOM, soil aggregate stability, soil water content,

nutrients availability, and soil biodiversity. Some of these inputs could be addressed to other soil impact.

- In Southern Europe, "No till" practices are more reported associated to an increase in soil quality. "Reduced till" is more reported in other regions. However, both practices are also reported to increase herbicide use when there is no mechanical weed control, although no quantitative studies were reported.
- **"Soil biodiversity"** was not among the most reported impacts, but it still collected considerable number of counts. It was reported for all ENZ with higher representation in LUS, MDM, and MDN. It was also reported for all ER, with higher representation in Western Europe.
- There were several SSP associated with the impact on soil biodiversity (16 practices out of a total of 30), mainly belonging to the group of crop and cropping system practices and nutrient management and crop protection. In the latest group, the use of organic fertilizers was the dominant practice associated as having impact on soil biodiversity. The "Cover/catch crops", "Crop rotations" and "No till" practices were also addressed by contributing partners.
- Impacts on soil biodiversity referred mainly to increase in earthworms and scarce quantitative evidence was provided on other parameters. "Cover/catch crops" and "Organic fertilizers" were addressed as SSP that increased soil biodiversity but only two-three partners from Southern Europe and Western Europe provided quantitative data on this impact.
- **"Farmers' profitability"** was among the five most reported impacts. It was reported for all ENZ with the exception of LUS, and had higher representation in CON and BOR. It was reported for all ER, with higher representation in Northern Europe.
- This impact is associated with many practices (27 out of a total of 30 practices), mainly belonging to the groups of soil tillage and cover, crop and cropping systems, and water management practices ("Reduced till", "No till", "Controlled traffic", "Cover/catch crops", "Drainage", "Efficient irrigation", and "Irrigation scheduling").
- The SSP "Cover/catch crops" is often reported, but the reports lack quantitative evidence on the farmers' profitability and also in other impacts.
- The impact of SSP on the farmers' profitability was many times reported as negative. In fact, this impact has the most negative reports in comparison with others. The major concerns are the initial costs of adopting sustainable soil management practices, either with investing money in equipment, technology, different fertilizers or soil amendments, or even when a farmers' income is reduced due to possible yield reductions. It is recognized by the scientific community that in the long-term the soil will benefit from the adoption of sustainable soil management practices. Inputs from partners indicate the need for more quantitative evidence on how the adoption of these practices impacts farmers' profits. Also, creating incentives on national/regional/EU level would help farmers to adopt these practices.

Adaptation to climate change:

- "Adaptation to climate change" was the 6th most reported impacts. It was reported for all ENZ (except LUS) and ER, with higher percentages in ATN and MDS and in Southern and Western Europe. This was likely due to actual higher impacts of climate change on agriculture in these areas.
- Adaptation to climate change was the main impact of SSP in the "Water management" group, where the most reported were: "Water use efficiency", "Efficient irrigation", "Irrigation scheduling", and "Water storage capacity".
- Also contributing to adaptation, were reported SSP to reduce soil erosion, improve soil structure, improve the soil water retention (e.g. "Direct seeding", "No till", "Reduced till", "Low pressure", "Controlled traffic", and "Crop rotation") or decrease surface temperature ("Mulching").
- Although, it could be expected that SSP relative to the efficient use of irrigation water would be more referred in Southern Europe, these are rather spread among ER. Countries such as NL and UK report an increased interest in irrigation in the face of climate change conditions and report quantitative results of studies on its economic viability.
- "Desertification" was almost absent in reported impacts and was only marginally reported in MDS and PAN. As desertification is a complex impact resulting from a set of degradation processes, it may have been considered individually by other impacts or soil challenges. Although, this can also mean that few studies are conducted considering the different impacts that can lead to the complex process of desertification, and which can be of varying nature in different contexts. This is somehow surprising as desertification can be of drastic and in some cases irreversible consequences and is an important risk in many ERs, mainly Southern Europe.

Mitigation of climate change

Mitigation of climate change by SSP was addressed in this synthesis by the soil challenges "Avoid N_2O and CH_4 emissions" and "Maintain increase SOC".

- "Avoid N_2O and CH_4 emissions" was one of the less reported challenges. It was marginally reported by most of ENZ and was not reported in Northern Europe.
- Some of the few practices reported in relation to this challenge were those that reduce soil mobilization and compaction ("No till", "Reduced till" and "Controlled traffic"). E.g., two quantitative studies evidencing the reduction of GHG from "No till" and "Reduced till" were reported (UK and IT); UK reported that the increase of C sequestration may be offset in damp conditions by increased emissions of N_2O from soil microbes.
- SSP related to fertilization were also reported ("Organic fertilizers" and "Efficient fertilization"). E.g., two quantitative studies evidencing reduction of GHG from the use of organic fertilizers were reported (IT and SP), and there was quantitative information on reduction obtained from methods for efficient fertilization; one study reported that biochar

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application into soil can increase N_2O fluxes (EE), on the contrary, another study reports that use of biochar increased SOC and decreased N_2O emissions (BE).

- Practices related to water management in paddy rice. One study was reported with quantitative results of methods (dry seeding and delayed flooding and alternate wet and drying) that decrease N_2O and CH_4 emissions in paddy rice (SP).
- One study with quantitative results for limiting GHG emissions of productive systems in former peatland was reported (LV).
- There was a low amount of reported studies about emissions of N_2O and CH_4 from agricultural soils. Furthermore, the few studies show sometimes contradictory results, pointing out to the complexity and low level of knowledge on these processes. This can be due to the fact that it has not been a central question for farmers, agronomists and researchers, as it is outside the traditional goals of agriculture. The reduction N_2O and CH_4 emissions from soils most likely need more research and/or dissemination of known practices.
- "Maintain/increase SOC" is also related to mitigation of climate change. This challenge is among the most reported and is present in all ENZ and European Regions, with less expression in Northern Europe.
- The SSP most reported to increase SOC those that reduce soil mobilization ("No till", "Reduced till", and "Direct seeding"); practices related to cropping system ("Crop rotations", "cover/catch crops", "Perennial crops", "Grasslands", "Permanent soil cover", "Hedges", and agro-forestry systems); practices related to the use of organic fertilizers. Several studies report quantitative results on the increase of C storage as a result of these practices (e.g. AT, IT, PT, SP, LT, FR, DE, DK, BE), indicating that the level of knowledge on C sequestration is higher than that of practices to avoid N_2O and CH_4 emissions.
- Some studies on reduced tillage report neutral effects on C storage (BE, FR, NO and PO); and negative impacts in SOC are reported from drainage practices in organic soils (DK) and case-specific use of organic fertilizers (NL).

Annex

Table 4. Quantified impacts for main soil management practices identified in the four managment groups: "Soil tillage and cover" (Table 4a), "Crop and cropping systems" (Table 4b), "Nutrient management and crop protection" (Table 4c), "Water management" (Table 4d).

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Table 4a. Reported impacts for main soil management practices identified in category "soil tillage and cover". Abbreviations: conventional tillage (CT), reduced tillage (RT), organic matter (OM), soil organic carbon (SOC).

Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality (erosion/combined impacts)	Soil biodiversity	Other biophysical	Farmers' profitability	Readiness for use
Non-inversion/ reduced tillage	Northern Europe	DK	Reduces P loss and N leaching.		Increases water aggregate stability at 0-10 cm depth in low-carbon clay soils. Problems with soil compaction below tillage depth.					
		NO		No significant effect in C content.		Prevents soil erosion.				
	Central Europe	AT	SOC, N, K and P higher in the topsoil compared to conventional tillage.			Increased OM in top layer, leading to more stable structure and water retention. Risk of erosion decreases up to 58%.		Herbicide application might increase.		More knowledge and competences to balance sustainable production and yield.
		CH			RT with mulching improved soil structure and SOC in 0-6 cm.					
		CZ				Decrease of soil water erosion.				
		DE				The concentration of SOC at the surface improves soil structure, increases water infiltration capacity, and reduces the risk of erosion.	Soil fauna profit from no-tillage in particular anecic earthworms.		Less workload and diesel costs. In drier regions can also increase the yield.	
		SI				(same as direct seeding)				
		LT	(same as direct seeding)	(same as direct seeding)					On sandy loam the yield of grain crops under RT was higher only 2 years out of 20. On loam, the result was 4 out of 20.	
	Western Europe	BE	Decreases risk of acidification; nutrients (mineral N and alkali) more concentrated in topsoil and less prone to leaching.	Redistribution of SOC, but an increase in C stocks is not confirmed by most studies.		Reduces up to 85% soil erosion.	Beneficial soil fungi in the 0-10 cm layer are favoured.			Demands changes to the whole crop system and new machinery. Compacted soil might need deep non-inversion till.

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality (erosion/combined impacts)	Soil biodiversity	Other biophysical	Farmers' profitability	Readiness for use
		NL	Increment of 400 kg N/yr (8 yr experiment on marine clay soil). A long-term experiment on sandy soils showed RT associated with lower N_{min} in autumn, reducing risk of leaching.	Higher organic matter concentration in the topsoil than in the subsoil. There is a tendency towards higher total soil organic carbon under RT. Evidence for this is uncertain in clay soils and limited in sandy soils.			Increase of diversity in earthworm population and a general increase of soil life.			
		UK				Reduced water losses, reduced soil erosion, improved soil structure, enhanced biodiversity, increase soil organic matter.		Potential for GHG mitig. due to increased C storage or reduced soil respiration. This may be offset in damp conditions by N_2O emissions from soil microbes.	Can reduce yields in some cases, but positive yield responses when combined with crop rotations.	
	Southern Europe	TR		(Same as NT)		Higher water content in soil.			The wheat yield was significantly higher under RT in18 out of 50 yr experiment. In pulse crop rotation, the wheat yield increment was not statistically significant.	

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality (erosion/combined impacts)	Soil biodiversity	Adaptation to climate change	Other biophysical	Farmers' profitability	Readiness for use
No till	Northern Europe	DK			Increase water content and improve soil structure in the top layer. Problems with soil compaction below seeding depth.			Reduce soil temperature in spring			
		NO		No significant effect in C content.	Topsoil SOM, aggregate stability, surface roughness	Prevents soil loss.					
		SE							NT and RT can lead to increased crop diseases and reduced yield, which can be attributed to difficulties in crop establishment.		
	Central Europe	AT				Reduce erosion up to 77%; more stable soil aggregates; accumulation of TOC and N in the topsoil; increase of biotic activity.			Negative: increased herbicide use.	Work and energy saving.	
		CH		(Same as direct seeding)	(Same as direct seeding)						
		SK									All agricultural soil in SK is mapped and suitability of soils for RT and NT are publicly available.
		SI				(same as direct seeding)					
		LT	(same as direct seeding)	(same as direct seeding)							
	Western Europe	FR		No effect on SOC stocks.	Increased hydraulic conductivity.	(same as for direct seeding)					

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		UK	Reduced nutrient and sediment run-off and loss. Less particulate P loss to waterways but increased loss dissolved reactive P.	Reduced erosion conserves OM.	Increased topsoil compaction can occur, leading to reduced porosity and high bulk density under NT. Other studies reported improved soil structure due to increased OM.	Reduced 5% Soil erosion.	Earthworm can increase 6-fold, creating open drainage channels through soil.				
	Southern Europe	IT	SOC and total N in the 0-30 cm layer clearly show a positive accumulation trend when (+17.3% and +10.4% respect.) in period1993 - 2008.	Higher SOC (g kg^{-1}) in 0–15 cm (19.7 vs 18.7) and at 15–30 cm (18.7 vs 15.0). The situation was reversed in 30–45 and 45– 60 cm. Higher SOM (~ 1%) in 0-5 cm. SOC stock increased by 0.3-0.4 Mg ha^{-1} yr^{-1}.		Soil water content about 20% higher during wheat cycle.	Earthworms 2 -3 times more numerous and more 30% microarthropods.		50-60% reduction GHG emissions due to reduced mineral fertilization	Less fuel consumption (-50 to 74%). Decrease yield of around 35 kg/ha, or no difference in winter wheat. Reduction of total costs (−19%) in paddy rice.	
		PT		No difference in SOC for mineral layers. SOC Mg ha^{-1}) higher for organic + mineral layers under NT (22.5 vs 12.2 for 0-10 cm; 34.2 vs 22 for 0-20 cm). NT also led to higher labile C at 0-10 cm (30 yr chestnut experiment).					Enhanced nuts production and fruit quality.	The estimated net income, including nuts, mushrooms and pasture was 4.341 € $ha^{-1}yr^{-1}$ for NT, compared to 1.725 €$ha^{-1}yr^{-1}$ for CT.	

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		SP		RT and NT respectively increased C seq. rate (Mg ha^{-1} yr^{-1}) by 1.54 and 1.40 (Meta-analysis RT, NT vs CT). SOC increased 96% in 0-10 cm; 58% increase in whole soil profile (3 yr experiment NT vs CT with irrigated corn). More 16% SOC and more 5% N; more 63% intra-microaggregate OM. The results show that microbes and their by-product are the most important pool of OM stabilization and C seq. in soils under NT (25 yr experiment NT vs CT with barley).	RT with incorporation of plant residues or green manure incremented micro-aggregates occluded within macro-aggregates by 75%; increased SOC within them by 130% compared to CT (4 yr experiment in almonds).	Total porosity higher in NT than CT (46.5% vs 43.8%) with more macroaggregates. Soil water content, water retention at field capacity and permanent wilting point higher in NT than CT (3 yr experiment NT vs CT with irrigated corn).				Corn biomass and yield was always higher in NT but the differences with CT varied during the three years (3 yr experiment NT vs CT with irrigated corn).	
		TR		Higher microbial C (C_{mic}) and C_{mic}/C_{org} ratios in NT.	Higher structure stability index in NT.					Lower production costs due to less fuel use.	

Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality (erosion/combined impacts)	Soil biodiversity	Adaptation to climate change	Other biophysical	Farmers' profitability	Readiness for use
Direct seeding	Central Europe	CZ				Decrease of soil water erosion.					
		CH		Improve SOC, but normally only in the top cm of soil.	Improve soil structure indirectly by no or reduced compaction at the ploughing zone.						
		SI				Can reduce CO_2 emissions, reduce erosion, lead to higher soil organic matter of the upper soil layer, and more resilient soil biology.				Can reduce costs.	
		LT	Nutrients and OM stratification and accumulation in very top-soil. Nutrients may become unavailable under drier climate change conditions.	SOC sequestration rate (Mgha^{-1} yr^{-1}) depends on texture. Seq. was 62% higher in loam than in sandy loam (17 years experiment).		The long-term cumulative effects show SOC accumulation, soil pore-size distribution, water release characteristics and CO_2 efflux on loam and sandy loam were better within a 0–10 cm of Cambisol.					
		EE		Higher SOC in 0-5 (stratification); no significant difference in 0-25 cm layer.		Higher fine aggregate stability, porosity and water holding capacity for 5-15 cm; no effect for 25-35 cm.				Energy and time saving.	
	Western Europe	BE				Improve soil structure, soil biodiversity, nutrients (C, N).		Improves the water infiltration and water retention, decreases the run-off and erosion.			Demands changes to the whole crop system. Few farmers are ready to adopt it. Needs more techno-economical evidences.

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		FR		No effect on SOC stocks.	Complex effects, increase in bulk density.		Increase earthworm galleries and biomass. Increase macro invertebrates (126 ind.m^{-2} vs 36 ind.m^{-2}) and increased diversity (41 taxa vs 31 taxa).				
		UK				Improved soil water retention and OM.			Can reduce GHG emissions 2-3 fold (maize).	Can reduce costs.	
	Southern Europe	TR		(Same as NT)	(Same as NT)						

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Table 2b. Reported impacts for the four main soil management practices identified in category "Crops and cropping system".

Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Desertification	Other biophysic	Farmers' profitability
Crop rotations	Northern Europe	DK		Enhance quality and quantity of SOM		Improvement					
		NO	Increase		Improve		Improve			Control of pests	
	Central Europe	CH						No clear evidence that crop rotation contributes to climate change mitigation			
		AT				Increase fertility		More resilience to climate change including the biotic stress and drought			
		CZ				Reduction of soil water erosion					
		DE		Variable						Decrease of soil borne diseases	
		HU	Increase				Improve				
		SK						By climate change, crops may have to be shifted to the lower regions, as for instance potatoes			The potential profitability rate of wheat in suitable soils is >25%. Its < 20% in less suitable soils; databases and map reports on the suitability of soils for cultivating plants have been developed.
		LT		Highest SOC (15.2 g/kg) was found under the crop rotation compared to green manure (11.3 g/kg)			The highest number of earthworms was found for sugarbeet after spring barley. The lowest was measured after continuous winter wheat and spring barley and pea after winter wheat.			The highest weed reduction was observed with spring barley preceding winter wheat than pea.	
		EE	Stable nutrient level								

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Desertification	Other biophysic	Farmers' profitability
	Western Europe	BE		Positive effect in the long term		Improve soil structure	Improve soil biodiversity	Plant species more adapted and resilient; decrease of biotic stress			Less consumption of agro-chemicals
		FR		Increase of SOC stock	Different rooting system improve structure						
		NL	N surplus in clay soils; N decrease in sandy soils; no effects on P-balance; best crop rotation: maize-grass/clover for 3 yrs	Crop rotation contributes less to SOM compared to permanent grassland							A less intensive crop rotation has a negative financial result; incorporation of bulbs in soil has a positive results; a maize-grass/clover rotation increases maize yield.
		UK	Cover crops can help to manage N, either by preventing leaching or additional input by N_2 fixation. Legume cover crops can be used to partly replace fertilizer inputs without compromising crop yield under intensive management and no till.					Changes in climate can change the frequency and persistence of pests and diseases. Crop rotations help to manage nutrients, pests and diseases in response to these changing stresses.			Crop rotations can minimise yield losses due to pests, diseases and weed infestations. Minimise the use of chemicals (fertilizers, herbicides and pesticides) which can be a huge cost to farmers.

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Desertification	Other biophysic	Farmers' profitability
	Southern Europe	IT	In MDN, there is an increase of soil N by 22% the organic farming compared to conventional farming	In MDS, the SOC increased by 5.1% and 4.4% , respectively under the rainfed and irrigated wheat forage rotation compared with mocrocrop; in MDN, the SOC increased by 37% in the organic farming with vegetables as compared to conventional system							
		SP		In MDS, the no till sequestered more SOC under the continuous wheat and crop rotation with faba bean; under conventional tillage, the continuous sunflower sequestered more SOC than any crop rotation	In MDS and MDN, crop rotations improve soil structure	In MDS and MDN, crop rotations reduce soil erosion, runoff and sediment losses, and soil fertility				In MDN, weed density and species richness were higher under monoculture than under crop rotation	
		TR		Higher total SOC was observed in surface soils of fallow-wheat and pulses-wheat rotations than in fallow and chickpea							

Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Desertification	Other biophysic	Farmers' profitability
Association/intercropping	Central Europe	AT	Reduction of chemical fertilizer	Increase of C turnover	Improve		Improve			Improve water retention and infiltration	

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	Western Europe	UK	Intercropping legume-cereal can improve crop yield, and N and P use efficiency with reduction of runoff rates and nutrient leaching. Increased rhizosphere processes as a result of intercropping facilitate nutrient uptake by crops		Intercropping reduces soil erosion		Abundance, diversity and activity of functional groups of soil biotic communities can increase by plant diversity				
	Southern Europe	IT									In MDN, Land Equivalent Ratio (LER) index of the maize-soybean intercrop was about 1.3. LER and 1.1-1.25 for barley-pea intercrop

Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Desertification	Other biophysic	Farmers' profitability
Cover/catch crops	Northern Europe	DK	Reduce of leaching losses			Enhance continuous macro-porosity and reduce soil compaction					
		NO	Prevent nutrient losses			Prevent soil loss					
		CH		Good source of C that directly contributes to SOC accumulation	Improve structure						
	Central Europe	AT	Prevent nutrient leaching	Increase of humic OM; moderate SOC increase	Reduce erosion by 25-60%						
		DE	Cover crops capture especially N which can be released in soil for the next crop	Build-up of +320 kg C/ha							

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		LT		Catch crops for green manure decreased soil N by 94.9% as compared with no catch crop	Highest reduction of soil bulk density (3.4%) occurred after incorporation of red clover						
		EE	The field bean catch crop was the most efficient to mitigate leaching								
		BEl	Enhance soil nutrient and avoid groundwater contamination	Maintenance/ increase of SOC							
		FR		Increase of soil C storage (+292 kg C/ha/yr)	Reduction of erosion by reduction of destructive effect of raindrops on soil aggregates and reduction of runoff						
	Western Europe	NL	Contribute to mitigate N surplus and increase crop yield in spring		Marginal effect, but the presence of earthworms my contribute to improve structure						
		UK	Cover crops maintain appropriate soil coverage during fallow periods, reducing risks of nutrients leaching and surface and groundwater pollution		Cover crops maintain appropriate soil coverage during fallow periods improving soil structure	Cover crops maintain appropriate soil coverage during fallow periods and protect it against erosion	Cover crops maintain appropriate soil coverage during fallow periods and promote soil biota			Cover crops contribute to wider ecosystem benefits	Cover crops contribute to weed suppression during crop growth with significant yield increases and economic benefits

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	Southern Europe	IT	In MDS, there is an increase of total N and P depending on cover crop sequence	In MDS, cover crops contribute to a 6% SOC increase in a flat area and 9% in sloping vineyard after 5 yrs	In MDS, sowing the appropriate cover crops can reduce erosion 68% compared with conventional tillage							

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		PT	In MDS, the highest biomass input to the soil from cover crops reduced runoff and N leaching when compared with conventional tillage	In MDS, the highest OM input to the soil from cover crops increased the soil C storage	In MDS, the inter-row cover crops in orchards has been largely adopted in Portugal to control soil erosion using especially a temporary soil cover by the low water availability	In MDS, intercropping in orchards with sown herbaceous vegetation increased SOM in 0-15 cm layer and improved the soil quality; clover contributed to maintain higher moisture in the topsoil; in traditional olives, the highest concentrations of SOC in 0-20 cm and 20-50 cm was 14.5 g/kg and 10.2 g/kg, respectively.	In MDS, the maintenance of soil cover with natural herbaceous vegetation increased the productivity of mushrooms in chestnut agroforestry system in the northeast Portugal	In MDS, ground cover vegetation can improve several ecosystem services		In MDS, the soil cover in Inter-row spacing affects positively the main crop by protecting from pests and diseases, e.g., by attracting auxiliary insects	In MDS, by adoption of irrigation and soil cover in the inter-row spacing, apple and pear productivity increased by 72% and 170%, respectively, and olives increased by 26-29%

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		SP	In MDS and MDN, permanent alley crops increased soil N but decreased soil P compared to mono-crop, but no effects were observed with annual intercrops; in MDN, barley was more efficient than vetch to mitigate the risk of nitrate leaching by reducing inorganic N in the top 4 m of soil depth; a conceptual model for total OC and total P losses was developed to estimate the impact of different cover crops in conservation systems	In MDS and MDN, the annual and permanent intercrop cover crops in orchards increased soil C storage by 0.43 Mg/ha/ yr and 1.01 Mg/ha/yr, respectively compared to monocrop	In MDN, barley was more beneficial than vetch as cover crop to enhance soil structure stability, water holding capacity, water infiltration rate, and saturated hydraulic conductivity compared to fallow		In MDS, greater plant diversity and increased the number of arthropod pests; in olive orchards, treatments combining tillage and herbicide were the most disturbing in terms of ecological descriptors of the nematode community and the soil food web. A minimum soil disturbance combined with cover crops can partially offset this impact. In MDN, microbial biomass C, and the B-glucosidase and urease enzymatic activities were higher under the natural vegetation than CT at 0-5 cm layer.		Tunoff in olive orchards was 8-9% higher in presence of cover crops than under conventional tillage. The DR2-2013© SAGA v1.1 model showed 2.3 times higher duration of time to ponding in conventional tillage, and 2.2% lower runoff in presence of cover crops.	In MDN, vetch was the only cover crop that increased N_2O emission in the intercropping; the incorporation of barley and rape residues in soil increased CO_2 fluxes during maize growth	

Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Desertification	Other biophysic	Farmers' profitability
Use of grassland/pasture with legumes	Northern Europe	DK	N input by N_2 fixation >100 kg N/ha/yr	Increase of C stock (1 t C/ha/yr) in grasslands; no data for mixed grasslands	Improve in the long term						
	Central Europe	CH					Mixed pastures improve diversity of insect and other pollinators, as well as soil microbial diversity				
		AT	Provide nutrients, especially N by legumes							Better control of weeds; more suitable for climate change than monoculture by a higher water use efficiency by different rooting systems	
		LT		Different types of clover–grass promoted OC immobilization in microbial biomass especially by influence of roots			Increase the microbial biomass C and N compared to arable land.				

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		BE		Contribute to C sink (stock of 14 g C/m^2); conversion of cropland into grassland contribute to 0.47-0.64 t C/ha/yr; grazing build-up higher C than mowing alone							
	Western Europe	NL	Grass/clover contributes to 200 kg N/ha/yr by presence of legumes		Permanent grassland contribute to improve soil structure by presence of different rooting systems and earthworms			Grass/clover contributes to reduce the GHGs emissions by about 6%			Grass/clover requires less mineral fertilizers; incorporation of clover in soil increases feed production by 18%. No positive effects were observed for grain legumes
		UK	Legumes provide N by N_2 fixation								N_2 fixation by legumes can reduce the amount of additional purchased inorganic N fertilisers. Forage legumes are also of considerable importance for ruminant feeding due to their high protein content, high buffering effect which reduces acidosis, and fairly high energy content. Combined with perennial grasses they provide a suitable diet for highly-productive animals

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	Southern Europe	SP	In MDN, in the agroforestry system, the shallow rooted shrub *Cistus ladanifer* reduced surface water content and the N and Mg availability under its canopy, but enhanced P and K; on the contrary, the deep rooted N_2-fixing shrub R*etama sphaeroacarpa* increased the surface water and N and Mg availability, diminishing the P concentration	In LUS, a mixture of grass with 20%legumes resulted in a net C sequestration at farm level of 0.006-011 Mg C/ha/yr in the less intensive cropping system, with a net increase of humic OM fraction							

Practice	European region	Cou ntry	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Desertification	Other biophysic	Farmers' profitability
Perennial Crops	Central Europe	CH		Pasture grasses have an extensive root system and contribute more to increase SOC compared to arable land			Most perennials are meadows and pastures in the mountainous regions which increase biodiversity				
		AT		Increase of humic OM fraction; medium impact on soil C storage		Reduce of soil erosion				Reduce of nitrate leaching and nutrients runoff	
		DE	Depend on type of perennial crops; legumes supply N by N_2 fixation		Only some perennials have potential to sequester C (*Miscanthus*, grass/clover)						

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	Western Europe	UK	Grassland soils are high in nutrients and are less prone to nutrient leaching through runoff					Climate change and milder winters in the UK could be impacting on key reproductive and dormancy-related events in perennial plants			Fewer costs associated with annual ploughing and harvesting
	Southern Europe	IT		In MDS, the soil C storage of about 8.5 t CO_2 ha/yr				In MDN, contribute to C storage by above- and belowground woody organs and/or soil associated with pruned wood, abscised leaves and mown grasses. In MDS, the perennial crops contributed to C sequestration			

Practice	**European region**	**Cou ntry**	**Nutrients in the soil**	**C storage in the soil**	**Soil Structure**	**Soil quality**	**Soil biodiversity**	**Adaptation to climate change**	**Desertification**	**Other biophysic**	**Farmers' profitability**
Mulching	Northern Europe	DK			Increase soil porosity			Reduction of soil evaporation and increase of water holding capacity at soil surface			
	Central Europe	HU				Improve	Improve				
		LT	Soil mineral N stock in the spring is reduced by addition of straw								

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	Western Europe	UK			Reduce damage of soil surface by protecting aggregates from raindrops effects	Reduces soil erosion, and nutrient and sediment losses by minimising soil surface exposure					
	Southern Europe	IT						In MDS, plastic mulch positively affects both biomass, yield and water use efficiency of muskmelon mainly by reduction of 40% of evapotranspiration, and the length of the crop cycle		In MDS, in early spring, legume cover crops have a high-potential for weed management in organic vegetable farming (reduction of weed biomass by 50% when compared with the control); in autumn, perennial legumes reduce weeds biomass by about 72%	In MDS, biodegradable plastic (Mater-Bi®in) on strawberry and the organic mulch in vineyard are good alternative to polyethylene film. Biodegradable mulch can be directly rototilled into soil, where it is degraded in 6-12 months, saving time and farmers' resources, but with an increase of accumulation of plastic wastes on soil surface

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		SP		In MDS and MDN, cover crops in woody plantations, urban wastes and agrifood by-products increased the soil C by 0.41-0.52 Mg C/ha/yr for the first 200 yrs when compared to the baseline							
		TR				Wheat straw mulch decrease soil salinity				Mulch increases soil water retention	Wheat straw mulch increases crop yield

Practice	European region	Cou ntry	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Desertification	Other biophysic	Farmers' profitability
Permanent soil cover	Northern Europe	NO			Improve	Prevent soil loss					
	Western Europe	BE		Contribute to C sink of 14 g C/m^2		Improve					Mandatory practice, but benefits for farmers are not clear

Practice	Europea n region	Cou ntry	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Desertification	Other biophysic	Farmers' profitability
Vegetated /grass buffer strips	Northern Europe	DK	Reduction of leaching								
		NO								Prevent of eutrophicatio n of waters	
	Central Europe	HU					Improves				

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		FR		SOC in grass strips is 2-3 times higher in surface soil than in ploughed soil	Reduction of about 98% of runoff and soil erosion; stabilization of soil aggregates						
		UK					Vegetated buffer strips enhance habitat heterogeneity and ecological connectivity, and promote pollinators and insect life to field margins that may positively impact on adjacent field biodiversity			Vegetated buffer strips mitigate diffuse pollution into freshwater systems	
	Southern Europe	IT			In MDN, grass strip reduces erosion from 8.15 Mg/ha to 1.6 Mg/ha, i.e. about 5 times less than erosion on bare soils						

Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Desertification	Other biophysic	Farmers' profitability
Hedges	Central Europe	AT				Protects against soil erosion, and the crops against the wind				Improve water balance with reduction of evapotranspiration	
	Western Europe	BE		Contributes to C sink at midway to forestry; conversion of			Good refugee for several animals and plant species			Increase of crop yield	Higher costs for farmers to maintain the hedges but benefits for farmers

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				arable land to grass strip resulted in increase of 160 t C/ha/yr							are not clearly demonstrated
		FR		Increase of +240 (90-460) kg C /ha/yr at 30 cm soil depth							
		UK		The undisturbed nature of hedgerows and regular inputs of OM result in an increase of SOC.	Hedgerows constitute corridors of undisturbed soil which receive regular inputs of OM		Hedgerows are rich in biodiversity and this in turn improves the biodiversity of adjacent fields				
	Southern Europe	IT									

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Table 4c. Reported impacts for the four main soil management practices identified in category "Nutrient use and management".

Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Readiness for use	Other socio-economic
Use of organic fertilizers	Northern Europe	DK	Negative: challenge in efficient use since to obtain the potential yield may lead to increased N leaching (difficult synchronisation as compared to mineral fertilizer). Mainly used on dairy farms.									
		NO	Maintain SOM and nutrient levels of soil	Decrease SOM degradation	Improve soil aggregation, structure, fertility							
	Central Europe	AT	Elevated SOM content affects soil structure by increasing aggregate stability, available water capacity and water infiltration. Soil N contents significantly higher and increased N supplying capacity. Some significantly increase P and K in the soil.						Increased biotic activity by compost amendment, microbial biomass and earthworm abundance, which enhances mineralization of OM and resistance against pests and diseases. Negative: can cause increased CO_2 and N_2O emissions			
		DE	Nutrients and their availability to plants, should be applied according to the nutrient demand of plants.	Long-term organic fertilisation can increase SOC on average by 6 t/ha.								

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Readiness for use	Other socio-economic
		SI				N pollution, soil protection, increased organic matter, nutrient cycling, increase soil water holding capacity, improve yield.						
		LT	Negative: availability of organic fertilizers has reduced (reduction in the number of animals). Straw is the main organic fertilizer in arable land. Cover crops and biochar are also used, but are negligible		Increase in root biomass of timothy and alfalfa in second year (increase of coefficient of biological productivity from 0.93 to 4.54 and from 0.75 to 1.71, respectively).	Negative: potential hazards due to heavy metals and organic persistent pollutants. Sewage sludge composts contain high molecular weight PAHs, and high amounts of N (2.98%), P (4.44%) OM (47.6%), and K (1.20%).						

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Readiness for use	Other socio-economic
		EE	Negative: Organic fertilisers may contribute in increasing GHG emissions. High-temperature hay biochar application into soil increases N_2O fluxes. Pig slurry and pig slurry digestate have similar impact on soil reaction, soil nutrient content and on nutrient leaching.									
		CH		Soils are enriched with C compared to those with only mineral fertilizer inputs.				Use of organic manure fertilizers has been shown to increase soil C and crop yields.				

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Readiness for use	Other socio-economic
	Western Europe	BE	Soil P status (used for policy support - fertilization legislation MAP)	SOC increased significantly (+ 13-17% - after 4-7 years of farm compost application) 1 ton C in the form of farmyard manure stores 0.20 ton C in the soil in the longer term. Below-ground biomass contribute a factor 2 to 3 more to SOC vs. above-ground biomass inputs (crop residues of silage and cereal maize). Use of biochar increased SOC and decreased N_2O emissions.	After 4-7 years of repeated farm compost application), higher pH-KCl (+ 0.10 - 0.42 pH units), significantly higher ammonium lactate extractable P and K, improvement of aggregate stability, reduced bulk density in the top layer (0.02 g cm-3 on average)	Application of OM improves SOC, biodiversity, structure, and improves the natural nutrient cycle and availability of nutrients. Stability of biochar impacts on soil quality apart from SOC increase is limited.	Significantly higher microbial biomass C in the farm compost experiment (+7-50%). Mean earthworm number and biomass increase of 60 earthworms m^{-2} and 12 g m^{-2} respectively. Higher relative (+ 7.6%) abundance of bacterivorous nematodes while the abundance of fungivorous nematodes hardly changed				The main issue is the accessibility to organic matter.	Reuse of nutrients and organic matter in circular economy in agriculture

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Readiness for use	Other socio-economic
		FR		30% of the organic C in sludge is easily mineralised by micro-organisms, this proportion drops to 10% after composting due to the loss of easily biodegradable organic matter during composting.	Less compaction with organic amendment. Hydraulic conductivity 6 to 7x higher under organic amendment attributed to the role of the earthworm macrofauna, whose abundance and biomass are strongly favoured by organic inputs.		Increase in the abundance of soil macrofauna. Increase of density values: 251 (±201) ind.m^{-2} with green waste and sewage plant sludge and 425 (±371) ind.m^{-2} for soil with cattle manure (versus an average density of 191 (±126) ind.m^{-2} in soil with no amendment).					

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Readiness for use	Other socio-economic
		NL		SOM slightly decreases with manure applied annually (38m^3/ha) and SOM increases when applying manure+ compost (16-29m^3/ha+6-20t/ha).		1% increase of SOM increases plant-available water by 0.6 mm. The % of SOM is related to soil compaction, N mineralization and N-uptake. Applying large amounts of organic material enhances soil biodiversity and resistance to pests and diseases.				Experiments indicate a yield increase of 7-10% when applying a combination of manure and compost, strongly affected by the initial SOC.		
		UK	Soil organic material influences soil microclimate, microbial community structure, biomass turnover and mineralisation of nutrients.			Soils in intensively managed areas are prone to degradation. Amendment of soils with organic manures helps restore soil quality.	Organic fertilizers, by increasing SOM content, will help promote biological and ecological functioning within soils.					

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Readiness for use	Other socio-economic
	Southern Europe	IT				Reduced nitrate leaching from water cycle (14.4 kg/ha to 1.4 kg/ha) with poultry manure.		50-60% reduction GHG emissions due to reduced mineral fertilization, and reduction of energy use (mainly Diesel fuel and mineral fertilization). Combining N_2O and CO_2 emissions ΔCO_2eq emitted in spring was no different for green manure with respect to Urea, and 49% lower in compost.		Negative: total costs for wheat organic management are higher and this is mainly due for the costs of organic fertilizer. Also reflected on negative value of the Gross Margin.		

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Readiness for use	Other socio-economic
		PT	TPOMW is especially rich in K, N and OM and improve soils with serious limitations in fertility. The by-product slow mineralization rate contributes to stock organic C in long time, also provides a large energy source for soil microorganisms, causing immobilization of N and depleting inorganic N from the soil solution.	SOC median was slightly higher in organic sites, but not statistically significant, in sites with long-term management periods (>10 years). N measured in crop residues have a partly significant correlation of low N in organic farming, which may lead to low mineralization rates and therefore higher SOC		by-product with high C/N > 25 that can impair soil degradation, especially by intensive crop management.				It has high K and N content that avoid the cost of fertilization for the farmers.		
		SP							Lower N_2O emissions for organic as opposed to synthetic fertilizers (23% reduction). 28% significant reduction in cumulative emissions for solid organic fertilizer.			

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Readiness for use	Other socio-economic
		TR						Use of biochar decreased CO_2 emissions and increased soil C content (7%).		biochar enriched with phosphoric acid had highest mean wheat yield (675 kg/ha), while the lowest mean wheat yield (598.7 kg/ha) obtained from plots practised tomato biochar (200 kg/ha). Use of biochar increased soil K content (49%).		

Practice	European region	Country	Nutrients in the soil	Soil quality	Adaptation to climate change	Other biophysic	Farmers' profitability	Readiness for use	Other socio-economic
Methods for efficient fertilization	Northern Europe	DK					increase the yield, reduce the costs and reduce N leaching (applied at economic optimal rates)		
	Central Europe	AT	Guidelines help in optimal nutrient supply to the soil. Soil nutrients should be analysed more often to make fertilization more efficient and in line with the actual demand			Guideline and nitrate regulation contributes to prevention of nutrient leaching (avoid the application of excessive amounts of fertilizer).		Content of the guidelines is readily applicable since it includes tables with required amounts of fertilizers/soil amendments depending on the situation.	

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		CZ	Better knowledge about nutrition status of the soils helps farmers to optimize the amounts of fertilizers.						
		DE					Increasing costs for nutrients makes farmers apply nutrients effectively. Strong positive environmental effects due to less N and P losses to adjacent ecosystems.		
		SK	Up to 47% of soils with low P content and 17% of soils with low K content (in the last national survey). To prevent further soil degradation to has to be addressed.				Increased farmers' profit. Yet no precise data is available on the income increase when fertilization recommendations are followed.		Increases Farmer's income and employment rates, expansion of the farm's share capital, and greater investment in production (didn´t quantify).
		LT	High soil moisture content and better crop emergence and growth using catch crops (winter wheat with chopped straw shallow incorporated). Increased N migration into deeper soil layers. Cultivation of catch crops reduced N-NO3 concentration in the soil filtration water (31.7–62.1 %, in heavy loam Cambisol).	Increased yield in winter wheat (2.69 - 2.71 t ha-1) in the soil fertilized with manure. Fertilization with manure (60 t ha^{-1}) has increaed the lupine-oat dry matter (DM) yield (4.55 t ha^{-1}).			Negative: To save costs, not all farmers calculate the nutrient balance (they are encouraged to do the Fertilization Plan at a field level).		
		EE	Humus balance model enables to estimate the changes field-by-field as well as an average of crop rotation. Site-specific fertilisation recommendations enhances nutrient use efficiency and knowledge-based production.						

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		CH			Framework to balance the net nutrient inputs/outputs from a given system with the goal to reduce negative environmental impacts. Reduction in 25% of N fertilizer application lead to reduction of 10 kg N ha-1 per year.				
		BE	Better managing of soil nutrients, avoiding waste and over-consumption of fertilizer. Just in time N fertilization in horticulture (using Ecofert model)				Precise fertilization decrease the cost for farmer		Better fertilizer management decrease the pressure on water resources
	Western Europe	NL	In the past 30 years: N-surplus decreased 32% and P-surplus decreased 70%. Less fertilizer is applied with more efficient techniques, which caused higher nutrient-use-efficiency. NL has the highest N-surplus compared to all European countries.						
		UK	Optimising nutrient applications to soil to meet agronomic requirements		Fertiliser recommendations help minimise environmental impact and should be reviewed annually and updated to match changing conditions.				
	Southern Europe	IT	The application of fertilization based on soil nutrient balance is expected to reduce nitrate leaching in the groundwater						

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		SP						Impact related to a more efficient use of fertilizers. Reduction in N application up to 57% have been reported when Decision Support Systems for fertigation have been applied.	
		TR					Economic pure N amount which must be applied to cotton was determined as15,35 kg/ha. Different level of $CaNO_3$ did not affect cherry yield while increase Ca content and harness of fruits. K_2SO_4 applications increased K content of fruit and it affected fruit quality.		

Practice	European region	Country	Nutrients in the soil	Soil Structure	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Readiness for use	Other socio-economic
Use of biofertilizers	Central Europe	AT	Negative: Difficult to verify the enhancement of nutrients and their uptake by plants in the field. Soil quality in AT is still relatively high, and thus, certain products might not unfold their full potential							Especially in organic agriculture. Some types of application are very user-friendly and do not require additional work.	Negative: Farmers might invest money without attaining positive effects (might not work in all conditions/environments).
		SI							Plant biomass increase		

		LT	Negative: Results of biofertilizers application are not evident.	Microbe distribution not significantly different in several aggregate fractions in acid and moderately limed soil. In intensively limed soil, there was tendency of microbe displacement from the smallest aggregate-size classes to the largest (1–2 mm).	N-fixation ability of inoculated plants increase the rate of photosynthesis and respiratory enzymes; therefore higher yields.						
		EE						Effects need to be specified within local pedo-climatic conditions. Studies results suggest continued research			

	Southern Europe	PT					With symbiotic N_2-fixing bacteria in biodiverse pasture legumes shows a N_2 fixation of 50-85%, reducing the application of mineral N-fertilizers. Inoculation for grain legumes leads to a N_2-fixation of 45-70%. White and yellow lupine inoculated with N-fixing *Bradyrhizobium* sp. N_2 fixation was not affected by soil tillage. Positive soil N input (>+69 kg N ha^{-1}) estimated for both lupine residues.		Using microbial biofertilizers, yields increase and in some cases avoids the application of mineral (N) fertilizers in permanent biodiverse pasture. Grain legumes fababean and chickpea may contribute to a soil N input of 5-19 kg N ha-1 by adding plant residues to the soil.		
		SP	Benefits of biofertilizers have to be determined in the Plant. Impacts much dependent on starting level. Increase of 8-20% in leaf N content when mycorrhizae where applied to lettuce plants.			Increases in the functional microbiota. Quantification has not been reported in the agronomic studies consulted					

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Practice	European region	Country	Nutrients in the soil	Soil Structure	Soil quality	Farmers' profitability
Use of soil amendments	Northern Europe	DK				Potential: Increased nutrient availability, increased microbial and earthworm activity, improved soil structure and aggregate stability.
		NO	Improve yields by liming			
	Central Europe	AT	Liming prevents toxicity of Aluminium (and other heavy metals), which becomes soluble at a pH below 5.0. Liming increases the availability of nutrients.		Avoid acidification in the long term	
		SI	Uses of lime to alter soil pH			
		LV				Increase yield by 0.5t $year^{-1}$ in a 8 year span wheat production after liming (calculations made by assumption)and results in a production gain of 80 EUR ha^{-1}, and total net gain is 41.6 EUR ha^{-1}.
	Western Europe	BE			Improves soil quality as a whole avoiding acidification and improving nutrient availability	practice increase yield, however farmers consider it as cost without any added-value.
		NL	Neutral: Experiment showed that various soil amendments on the basis of CaO increased pH, but did not affect CEC, soil structure, infiltration capacity or soil life. Results show that amendments did not significantly affect yields. Positive: Experiment shows that liming increases pH and prevents crops taking up large amounts of Zn, Pb and Cd from contaminated soils.	Negative: The direct effect of applying CaO could improve the soil structure, especially in clay soils is not supported by research in the Netherlands.		

Table 4d. Reported impacts for the four main soil management practices identified in category "Water management".

Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Other socio-economic
Drainage systems	Northern Europe	DK	Loss of N and P	Decrease C storage, especially for organic, lowland soils				Increased GHG emissions		
		NO			Improve condition for crops and increase infiltration.					
	Central Europe	AT				Drying wetlands diminishes biodiversity. Renature drained fields would improve biodiversity and microclimate		Rain events after fertilization can lead to heavy nutrient loads to waters via drainage		Cropland is made available otherwise it would be too wet for agricultural production

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil quality	Soil biodiversity	Adaptation to climate change	Other biophysic	Farmers' profitability	Other socio-economic
		CH							In peatlands (i.e. organic soils with high water table), drainage enables cultivation. In mineral soils drainage can improve fertility and manageability.	
		DE			Necessary for cultivation in clayey soils, soils with hard pans and high ground water table					
	Western Europe	NL	Controlled drainage system can retain water and nutrients during the growing season. An experiment in NL shows a reduction of 20% N_{min} and a reduction of 50% N leaching.				Although not quantified, several field experiments show that controlled drainage improves water availability.			
		UK	Reduces the period of waterlogging which can increase denitrifying bacteria in anaerobic, saturated soils, leading to increased N loss via denitrification				Adverse weather, intensity and frequency of storm are increasing in UK due to climate change. Drainage systems need to be constantly repaired and updated in response.		Relief of excess water and control the water table thereby improving yields and grazing conditions and reducing the volatility of adverse weather periods.	
	Southern Europe	IT						Dry seeding and delayed flooding (PF) and alternate wet and drying (AWD) methods in paddy rice lower GHG emissions. The methods reduce CH4 and increase N2O, but Global Warming Potential (GWP) reduces (larger decrease in PF than AWD).		

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Practice	European region	Country	Nutrients in the soil	C storage in the soil	Soil quality	Adaptation to climate change	Farmers' profitability
Improve water storage capacity	Northern Europe	NO			Decreases erosion.		
	Western Europe	NL	Improving the water infiltration capacity reduces surface runoff and nutrient leaching.			Better prepared to face dry periods and heavy rainfall.	
		UK	Reduction in runoff reduces nutrient loss. Reduces particulate P delivery to freshwater systems.	Vegetation cover is important to reduce soil and C losses	Poor infiltration capacity of soil increases the potential for erosion and surface runoff.		
	Southern Europe	PT				To increase irrigation efficiency and avoid runoff, mini-basins proved to increase surface water storage.	
		SP				In the Guadiana River Basin, Managed Aquifer Recharge (MAR) can increase the total recharge in 48 $Mm^3\ yr^{-1}$. In Castilla y León MAR was initiated to recharge 0.4 $Mm^3\ yr^{-1}$. In Madrid, MAR optimization increased water availability up to 5 $Mm^3 yr^{-1}$.	
		TR				Comparing water harvesting techniques, snow curtains achieved better results, measured in higher grassland yield when compared to cubby, stone strips and contour furrows.	Contour furrows were the most economic, while snow curtains were not economically viable due to high construction cost. Using micro basin water harvesting in a barren land, higher pumpkin yields were obtained in areas of 100 and 120 cm ridges of covered black plastic mulch than those 80 cm

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Practice	European region	Country	Adaptation to climate change	Desertification	Farmers' profitability	Other socio-economic
Efficient irrigation systems	Central Europe	AT		Irrigation secures and/or increase crop yields in face of increased drought events. Implementation of irrigation must be scrutinized regarding sustainability		Irrigation systems are expensive and rarely economically viable.
		CH	Proper irrigation techniques may increase quality and quantity of harvest. Improper use may lead to nutrient losses (superficial, leaching, gaseous) and soil structure/erosion – depends strongly on site, situation, and farmer skills.			
	Western Europe	BE	Improve water and nutrient use efficiency for a better adaptation to climate change			
		NL	A field experiment shows that drip irrigation reduces irrigation water use by 50% compared to the conventional system. Irrigation also increased the plant available water and improved the nutrient uptake.		Recent droughts draw attention to efficient irrigation. Experiments with drip irr. of potato show that the yield increase outweight the costs (costs ~ k€1.3 ha^{-1} (2 mm/ha/day), yield increase is k€1-k€4 ha^{-1}). The profitability of irrigation is uncertain because it depends on the weather.	
	Southern Europe	IT	Localized low-pressure irrigation methods (drip, sprayers and capillary sub-irrigation) have higher water use efficiency and are used mainly for irrigation of orchards and vegetables in areas where water supply is limited.			
		SP	Drip irrigation should increase on-farm WUE from 10 to 40%. Subsurface drip irrigation will reduce water use from 5 to 30% depending on the crop type. Higher water savings can be achieved in deciduous crops. In woody perennials, regulated deficit irrigation allows water savings from 10 to 35% depending on the crop (less savings in citrus and higher water saving in early ripening stone fruit and grapevines).			
		TR			Comparison of surface drip irrigation (SDI) and subsurface drip irrigation (SSDI) in grapes between 2015-2017, the total irrigation water was 125-274 mm for SDI, and 103-223 mm for SSDI. The plant water use for SDI was 40-527 and 332-472 mm for SSDI. Generally, net income decreased in conjunction with decreasing irrigation amount.	

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Practice	European region	Country	Soil quality	Soil biodiversity	Adaptation to climate change	Farmers' profitability	Other socio-economic
Irrigation scheduling	**Central Europe**	**NL**			An irrigation on the basis of soil moisture sensors can save water. This effect was estimated to be ~50%.	Soil moisture sensor cost k€1-2. For an average arable farm, irrigation based on moisture sensors could increase the farms' income by €292 ha^{-1} yr^{-1}, save 25 labour hours and 10% fertilizer.	
	Southern Europe	**PT**	Modelling soil water dynamics and solute transport allows the optimization of irrigation scenarios according to soil properties, climatic conditions, crop species and irrigation water quality, preventing salinisation risks.				
		SP			WUE improves by scheduling irrigation based on evapotranspiration models. The gains depend on the initial WUE and the crop (7% in vegetables, up to 26% in woody crops, such as citrus).		
		TR				(same as for efficient irrigation systems)	

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