Report on the integration and synthesis of Study Site results and their potential for upscaling

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Report number:	**42**
Deliverable:	**D6.1**
Report type:	**Scientific Report**
Issue date:	**15 November 2021**
Project partner:	**RIKS**
Version:	**1.0**

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SoilCare
SOILCARE FOR PROFITABLE AND SUSTAINABLE CROP PRODUCTION IN EUROPE

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DOCUMENT SUMMARY

Project Information	
Project Title:	Soil Care for profitable and sustainable crop production in Europe
Project Acronym:	SoilCare
Call Identifier:	H2020-SFS-2015-2b
Grant agreement no.:	677407
Starting Date:	01.03.2016
End Date:	31.08.2021
Project duration	66 months
Web-Site address:	www.soilcare-project.eu
Project coordinator:	Wageningen Environmental Research (WEnR)
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Report Information	
Report Title:	Report on the integration and synthesis of Study Site results and their potential for upscaling.
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Deliverable Number:	D6.1
Work Package:	WP6
WP Leader:	RIKS, the Netherlands
Nature:	PU
Dissemination:	Document
Editor (s):	Rudi Hessel
E-Mail(s):	rudi.hessel@wur.nl
Telephone Number(s):	+31 317 486530
Report Due Date	01-12-2020
Report publish date:	15-11-2021
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5	University Hohenheim	UH	Germany
6	Research Institute for Knowledge Systems	RIKS	Netherlands
7	Technical University of Crete	TUC	Greece
8	Joint Research Centre	JRC	Italy
9	University of Bern	UNIBE	Switzerland
10	Milieu LTD	MLTD	Belgium
11	Norwegian Institute of Bioeconomy Research	NIBIO	Norway
12	Bodemkundige Dienst van België	BDB	Belgium
13	Aarhus University	AU	Denmark
14	Game & Wildlife Conservation Trust	GWCT	United Kingdom
15	Teagasc	TEAGASC	Ireland
16	Soil Cares Research	SCR	Netherlands
17	Instituto Politecnico De Coimbra	IPC/ESAC	Spain
18	National Research and Development Institute for Soil Science, Agrochemistry and Environmental Protection	ICPA	Romania
19	University of Padova	UNIPD	Italy
20	Institute of Agrophysics of the Polish Academy of	IAPAN	Poland
21	Wageningen University	WU	Netherlands
22	University of Pannonia	UP	Hungary
23	Swedish University of Agricultural Sciences	SLU	Sweden
24	Agro Intelligence Aps.	AI	Denmark
25	Crop Research Institute	VURV	Czech Republic
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Executive summary

The SoilCare project studied the adoption of sustainable agricultural practices, referred to as 'soil-improving cropping practices (SICS)', in particular those related to improving soil quality. To do so, it looked across various scales (from local to European level) at the biophysical, socio-cultural, economic, political, and technological factors impacting on adoption of these practices.

To integrate and synthesize results from different study sites and existing data sources the SICS Potential Index has been developed as part of WP6. The development of the SICS Potential Index has been an iterative process throughout the project involving Study Site partners and their stakeholders, as well as modelling partners. As part of the process use was made of expert opinion (from study site partners and stakeholders through questionnaires and personal communication), publicly available Europe-wide data, and model results from the SoilCare Integrated Assessment Model (IAM) developed as part of the SoilCare project.

The SICS Potential Index is a spatially-explicit approach that consists of three main components - applicability, relevance and impact - which together provide an understanding of the potential to apply a specific SICS or SICS group across Europe and thus helps to understand the transferability of SICS tested in the study sites to other regions in Europe. The SICS Potential Index maps are complemented with a description of additional adoption factors less suitable to be captured at a high level of spatial detail.

This deliverable describes the methodology that has been developed and applied, together with the applicability and relevance results for 23 SICS that have been investigated in the SoilCare study sites. In addition, the deliverable provides applicability, relevance and impact results for key SICS (cover crops, mulching, minimum tillage and compaction reduction), for which impact modelling could be carried out with the SoilCare IAM. All results are available through the SoilCare Interactive Mapping Tool (D6.3) as well.

Table of contents

1. Introduction

European agriculture faces a real challenge: it must reduce its negative environmental impacts but also remain competitive. A key area of concern is the ongoing degradation of agricultural soils, which is likely to increase further in the coming decades because of climate and socio-economic developments (European Environment Agency, 2019; Mission Board for Soil Health and Food, 2020). While there are well-known agricultural management techniques that can help to improve soil quality, uptake of these techniques remains low in Europe - despite various policy incentives (McNeill et al., 2018, 2020).

The SoilCare project studied the adoption of sustainable agricultural practices, in particular those related to improving soil quality. To do so, it looked across various scales (from local to European level) at the biophysical, socio-cultural, economic, political, and technological factors impacting on adoption of these practices.

D6.1 reports on task 6.1 of the SoilCare project and as such looks to synthesize and integrate the results from the different Study Sites with existing data sources. It does so by assessing the extent to which Study Site results: i) are transferable to other regions in Europe and under what circumstances, and ii) can be up-scaled to provide pan-European information.

To integrate and synthesize results from different study sites and existing data sources the SICS Potential Index has been developed as part of WP6. Many important factors impacting on the potential of SICS to be applied to a certain location and in a specific context are spatially explicit (e.g. climate, soil, and land use characteristics) and therefore we have selected a spatially explicit approach to develop the SICS Potential index. However, not all adoption factors are relevant or available at a high level of spatial detail. We therefore complemented the SICS Potential Index maps with a description of additional adoption factors less suitable to be captured through a set of maps.

The development of the SICS Potential Index has been an iterative process throughout the project, involving Study Site partners and their stakeholders, as well as modelling partners. As part of the process use was made of expert opinion (from study site partners and stakeholders through questionnaires and personal communication), publicly available Europe-wide data, and model results from the SoilCare Integrated Assessment Model (IAM) developed as part of the SoilCare project.

The methodology that has been developed and applied to create the SICS Potential Index is described in Chapter 2 and its results in Chapter 3. Section 3.1 reports on the results from the SICS tested in the different Study Sites, while Section 3.2 reports on SICS for which impact modelling is carried out using the SoilCare Integrated Assessment Model (IAM), developed as part of the SoilCare project. Chapter 4 presents conclusions and recommendations for further work.

To disseminate the results of the SICS Potential Index, the SoilCare Interactive Mapping Tool (IMT) has been developed as part of the project. This tool includes all processed results and is freely available through the SoilCare project website: https://www.soilcare-project.eu/resources/mapping-tool or directly through imt.soilcare-project.eu. Deliverable 6.3 provides further information on the SoilCare IMT.

2. Methodology for creating the SICS Potential Index

The assessment of the potential to apply SICS across Europe is split into various components:

A. Applicability: where can a SICS be applied? Are there any climate, soil, land use or socio-economic limitations in applying the technique?

B. Relevance: where is it relevant to apply a SICS? Are there specific threats the SICS can mitigate? Or is there an aim to improve certain soil quality aspects through applying the SICS?

C. Impact: what is the impact of applying the SICS on sustainability and profitability indicators, including soil quality indicators?

An overview of the process to create the applicability, relevance and impact maps, as well as the SICS Potential Index is provided in Figure 2.1. Components A and B are developed using a combination of European-wide maps – the *Applicability base maps* and the *Relevance base maps* – and expert judgement. More information on the maps and related data sources is provided in Section 2.1. The expert judgement information is collected through a questionnaire (see Annex 1), from which information is extracted in a spreadsheet. Using an automatic procedure, the SICS-specific information from the spreadsheet is applied to the base maps to create per SICS a set of maps for the *Applicability to implement the SICS* and the *Relevance to apply the SICS*. These maps are the interpretation of the applicability and relevance for a SICS, based on one specific factor as represented by one base map. Categories on the applicability maps are 'applicable' (2), 'not preferred' (1) and 'not applicable' (0) and on the relevance maps the categories are 'relevant' (1) and 'not relevant'. Next, the set of *Applicability to apply the SICS* maps is merged into one *Combined applicability* map by taking the minimum value across these maps, implying that a restriction in any of the base maps results in a restriction to apply the SICS at that location. The *Relevance to apply the SICS* maps are combined into the *Combined relevance map* by taking the maximum value across the maps, indicating that a location is relevant for applying the SICS as long as it is relevant for at least one of the relevance factors at that location.

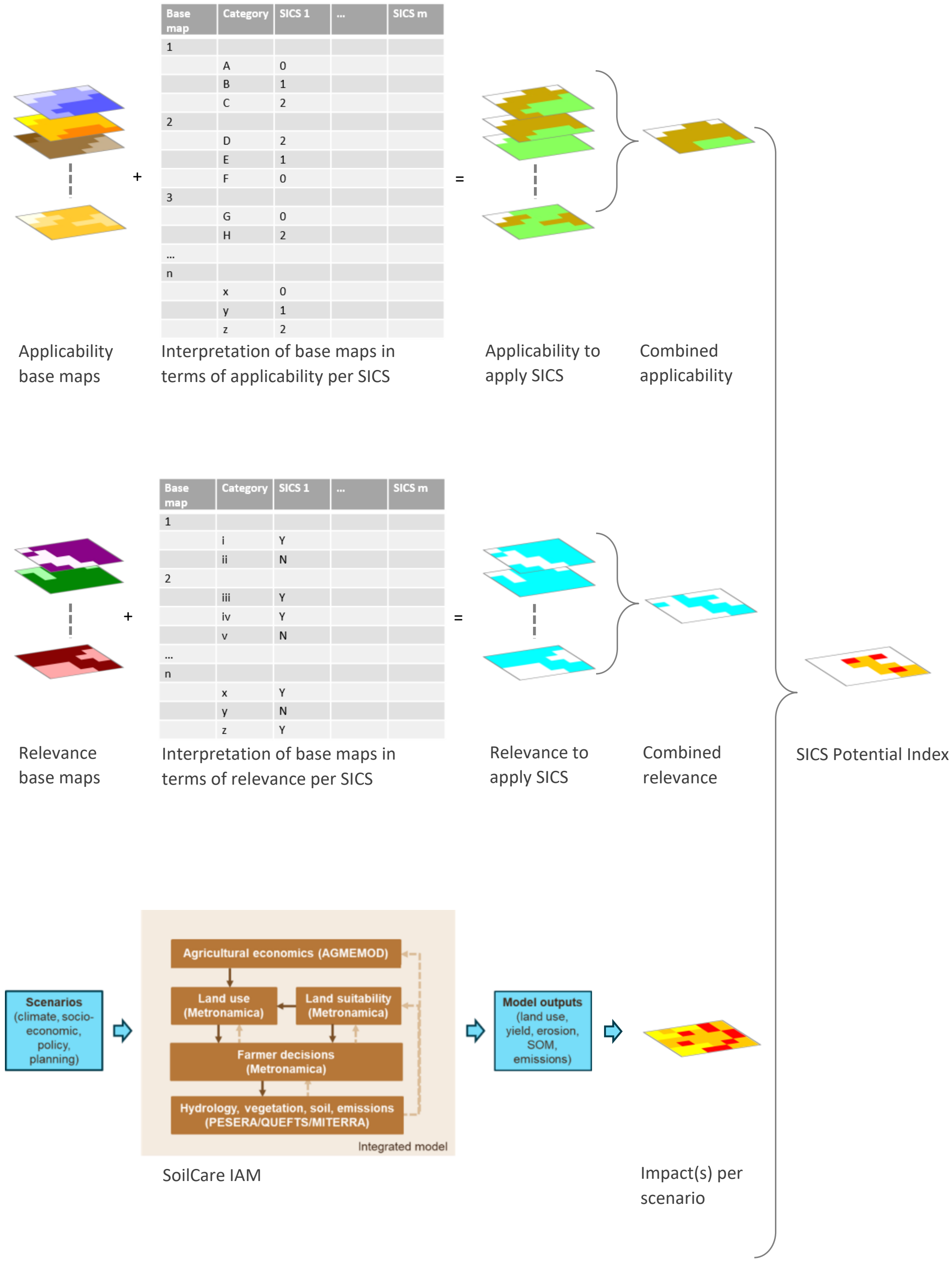


Figure 2.1: Methodology for calculating the SICS Potential Index as a combination of applicability, relevance and impact.

For component C, calculating the impact of applying a SICS, we make use of the SoilCare Integrated Assessment Model (IAM), developed as part of the SoilCare project. This model is applied to Europe at a 100-500 m resolution and includes land use, land management and biophysical components. It is used as part of the SICS Potential Index to calculate the impact of selected SICS (cover crops, mulching, minimum tillage and compaction reduction) on the indicators soil organic carbon (SOC), water erosion and crop yield. These indicators respectively serve as sustainability (SOC, water erosion) and profitability (yield) indicators. These indicators are calculated at local, cellular level by the PESERA (Kirkby et al, 2008) and QUEFTS (Janssen et al., 1990) models for integration into the SICS Potential Index, but also aggregated to regional level where they, together with model results on nitrogen emissions from the MITERRA-Europe model ((Velthof et al., 2009; de Vries et al., 2011), provide regional level impact of SICS application. More information on the SoilCare IAM can be found in Section 2.2 of this report and in deliverable *D6.2 Report on the potential for applying soil-improving cropping systems across Europe*. For each indicator, result maps from the SoilCare IAM are next classified into low (1), medium (2) and high (3) impact.

Using the information from A (applicability), B (relevance) and C (impact) we subsequently calculate a *SICS Potential per Indicator* type and an overall *SICS Potential Index* combining also the different impacts into this final indicator. For these final calculations we first combine the *Combined applicability* and the *Combined relevance* map by using the relevance map as a mask for the applicability map and hence show what the applicability is within the areas of relevance. This results in a *Combined applicability/relevance (Combined A/R)* map that shows within the relevant areas the applicability value (0, 1, 2).

We next combine this map with each individual sustainability and profitability indicator map (i.e. SOC, erosion, yield) into the SICS Potential per Indicator by creating a map according to the classification in the table below. As described above we have already reclassified each individual indicator map to have locations (cells) categorized into having low (1), medium (2), or (high) impact.

Table 2.1: Approach for integrating the Combined A/R map with specific impact indicator maps to create SICS Potential per Indicator maps.

Impact → Combined A/R ↓	1 (low)	2 (medium)	3 (high)
0 not A/R	0	0	0
1 relevant, but not preferred	1	2	3
2 applicable and relevant	2	3	4

In applying Table 2.1, we create a SICS Potential per Indicator map with 5 classes: 0 (no potential), 1 (low potential), 2 (medium potential), 3 (high potential), and 4 (very high potential). This then gives us a SICS Potential for improving or maintaining SOC, a SICS Potential for water erosion control, and a SICS potential for crop yield.

Finally we create the overall SICS Potential Index. To give equal weight to the sustainability and profitability aspects, we first combine the sustainability indicators (SOC and water erosion control) and next we combine these with the profitability indicator (yield). This approach considers local agricultural production potential, for which a stable SOC content (as soil health indicator) and erosion control are preconditions. Because all indicators are calculated with one integrated model (the SoilCare IAM), interactions between these indicators when applying a SICS are automatically included.

Combining the sustainability indicators follows a similar approach as above. Using the classified impact maps we create a *Sustainability impact* map according to the mapping scheme provided in Table 2.2.

Table 2.2: Approach for integrating the SOC and erosion maps into a Sustainability impact map.

Impact on erosion→ Impact on SOM↓	1 (low)	2 (medium)	3 (high)
1 (low)	1	2	2
2 (medium)	2	2	3
3 (high)	2	3	4

Next we combine the sustainability and yield impacts using Table 2.3.

Table 2.3: Approach for integrating the sustainability and the profitability (yield) map into an Integrated impact map.

Impact on yield → Impact on sust.↓	1 (low)	2 (medium)	3 (high)
1 (low)	1	2	2
2 (medium)	2	2	3
3 (high)	2	3	3
4 (very high)	3	3	3

And finally, we combine the Integrated impact map with the Combined A/R map into the overall SICS Potential Index according to Table 2.4.

Table 2.4: Approach for integrating the Combined A/R map with the Integrated impact map to create the overall SICS Potential Index map.

Impact → Combined A/R↓	1 (low)	2 (medium)	3 (high)
0 not A/R	0	0	0
1 not preferred	1	2	3
2 applicable	2	3	4

To complement the approach at grid-cell level, we also created some regional level impact maps. The regional maps allow the consideration of sustainability aspects that go beyond the farm-scale, e.g. of pollution issues. Indicator maps for the regional impact assessment were made by using the MITERRA-Europe model and regional aggregates of the gridded SOC, erosion and yield maps, thus providing information on: N leaching and runoff, N surplus, SOC (as carbon sequestration indicator), aggregated erosion and production.
Because not all adoption factors can be provided as spatially quantitative information, a descriptive summary of additional adoption factors is provided with each SICS potential index. This information is collected through the WP6 questionnaires and complemented with information from the other WPs, in particular WPs 3, 4, 7 and 8.

As part of D6.1, the SICS Potential Index has been calculated using the present-day data. The approach is, however, flexible to also include data for future years. This is demonstrated in D6.2 where base maps (land use, water erosion, SOC) and impact maps (water erosion, SOC, yield) for present conditions, 2030 and 2050 as calculated by the SoilCare IAM are used for the calculations, thus providing an assessment of the changing potential of SICS over time.

2.1 Application of the method

The method to create the SICS Potential Index has been applied for specific SICS investigated in the study sites and for four SICS at European scale included in the SoilCare Integrated Assessment Model (IAM) intended for Europe-wide impact assessment. The specifics of the application of the method for both groups of SICS are provided in the sections below.

2.1.1. SICS investigated in the study sites

In each of the SoilCare study sites one or more SICS have been investigated (see e.g. D5.3 and D7.2). As part of this deliverable, we assess to what extent the investigated SICS can be applied across Europe.

The specifics of the SICS investigated in the study sites were often too detailed to be modelled by the SoilCare IAM at European scale. We therefore followed the approach as presented above up to the creation of the Combined A/R maps. For each study site 1-3 SICS were selected for application of the method, resulting in a total of 23 SICS for which *Combined applicability*, *Combined Relevance* and *Combined A/R* maps have been created at European scale.

In collaboration with study site partners a decision was made on the relevance factors to be included for the SICS that were investigated in their study site. Furthermore, it was discussed if their SICS would likely have a major or a minor impact in mitigating the threats or stimulating the soil quality issues listed in the relevance factors. *Combined Relevance* and *Combined A/R* maps have next been created for each relevance factor individually as well as for combinations of relevance factors to understand the applicability of their SICS for individual and combined aspects. For each SICS a key relevance factor is included in this report and using that relevance factor the *Combined A/R* maps have been created. In the SoilCare Interactive Mapping Tool (D6.3) the *Combined A/R* maps per SICS have been created for each individual relevance factor found important as well as the combination of the selected relevance factors for that SICS.

To fine-tune the approach and improve the resulting maps and settings SICS, results were discussed with study site partners who again discussed them with the stakeholders in their region. During a first round of interactions, it was found that it was very difficult for local and regional experts and stakeholders to think about the broader applicability and transferability of their SICS, which were often tested at field level, across Europe. We therefore decided to create regional or national maps in addition to the Europe-wide maps, to facilitate the interpretation of the maps by local and regional experts and stakeholders. These maps proved to provide information relevant for local/regional experts, as the SICS tested in SoilCare were often innovative practices, for which there are still many questions about applicability, relevance and impact, also at the smaller spatial scale and for those operating at national and regional level.

To facilitate this process, a slide deck was made for individual study sites showing all steps from base maps, interpreted base maps (*Applicability to apply the SICS* and *Relevance to apply the SICS*), and combined maps (*Combined applicability*, *Combined relevance*, *Combined applicability/relevance*). These slide decks per study site are available through the SoilCare Interactive Mapping Tool.

2.1.2. SICS modelled at European scale

The SICS investigated in the study sites, have been grouped into 4 categories. For each category an example SICS has been defined, using information from specific SICS (as applied in study sites) that fitted the category, and also taking into account practical considerations such as the ability of the different models in the SoilCare IAM to model the effects of a particular SICS. For this type of analysis, the following categories of SICS were used:

- Soil improving crops: Cover crops
- (Organic) amendments: Mulching
- Soil cultivation: Minimum tillage
- Alleviation of compaction: Compaction alleviation

For these four example SICS (cover crops, mulching, minimum tillage and compaction alleviation), the full SICS Potential Index methodology has been applied.

Settings for the applicability and relevance base maps have been selected based on the settings for related SICS that were investigated in the study sites, and the SoilCare IAM was applied to calculate the SOC, water erosion and yield impact of each of the example SICS.

For the classification of the SOC and yield impact maps, the median and standard deviations of all maps for which the impact information was available (2030 - representing 10 years after the first implementation of SICS in the present day, and 2050) were analysed. Using this information, a table was constructed using +1 StDev to choose the value for medium impact, and +2 StDev for high impact. This resulted in the following classes:

- SOC content: medium impact > 10% increase, high impact > 30% increase.
- Yield: medium impact > 5% increase, high impact > 20% increase.

For categorizing the erosion, the erosion information was divided into a reduction of the erosion risk class and a reduction of the erosion rate. The idea behind this is not to classify only large erosion decreases, but also accounting for smaller decreases that reduce erosion to tolerable rates. This resulted in the following steps:

<u>Step 1:</u> Define the erosion *risk* classes: high risk > 2 ton/ha·yr, medium risk > 0.5 ton/ha·yr, low risk < 0.5 ton/ha·yr and categorize the maps with and without application of the SICS accordingly. The classes result from an aggregation of the ones used for the European soil erosion map produced by the JRC (Panagos et al., 2015), with the lowest class within the interval of tolerable erosion rates in Europe (0.3 to 1.4 ton/ha·yr; Verheijen et al., 2009).

<u>Step 2:</u> Assess the reduction in erosion risk class(es) for each location (cell) due to application of the SICS. Negative/low reduction: no change or increase, medium reduction: decrease of 1 class, high reduction, decrease of 2 classes.

<u>Step 3:</u> Define the reduction of erosion *rate* classes: low rate < 1 ton/ha·yr (hence, erosion rate decreases by less than 1 ton/ha·yr), medium rate <10 ton/ha·yr, high rate > 10 ton/ha·yr and categorize the maps with application of the SICS accordingly. In this case, the rates were arbitrarily chosen to represent an interval with one order of magnitude difference.

Step 4: Develop the final categorized erosion impact map by taking the maximum of the reduction of erosion risk class (negative/low, medium, high) and reduction of erosion rate (low, medium, high).

With the categorized SOC, water erosion and yield impact maps and the *Combined applicability/relevance* maps, the *SICS potential per indicator* and the overall *SICS Potential Index* were developed for cover crops, mulching, minimum tillage and compaction alleviation.

For each (category of) SICS we finally calculated the sustainability (N leaching and runoff, N surplus, SOC, erosion) and profitability (production) impacts at regional level, by using the MITERRA-Europe model and by aggregating the grid maps to NUTS-2 level.

Results for these 4 example SICS are provided in Section 3.2 and in the SoilCare Interactive Mapping Tool.

2.2 Data sources for calculating applicability and relevance

The following Europe-wide maps were used to calculate the applicability and relevance maps. On the next pages more information on these maps and their source is provided.

Applicability:

Climate

1. Precipitation
2. Aridity index

Soil:

3. Landform
4. Slope
5. Soil depth
6. Soil fertility
7. Texture

Socio-economic

8. Land use

Relevance

9. Erosion by wind
10. Erosion by water
11. Organic matter content
12. Soil compaction
13. Biological functions at risk
14. Soil fauna at risk
15. Soil micro-organisms at risk

From the list on the previous page, maps 6, 12, 13, 14 and 15 were taken from the European Soil Data Centre (ESDAC) (Panagos et al, 2012).

1. Precipitation

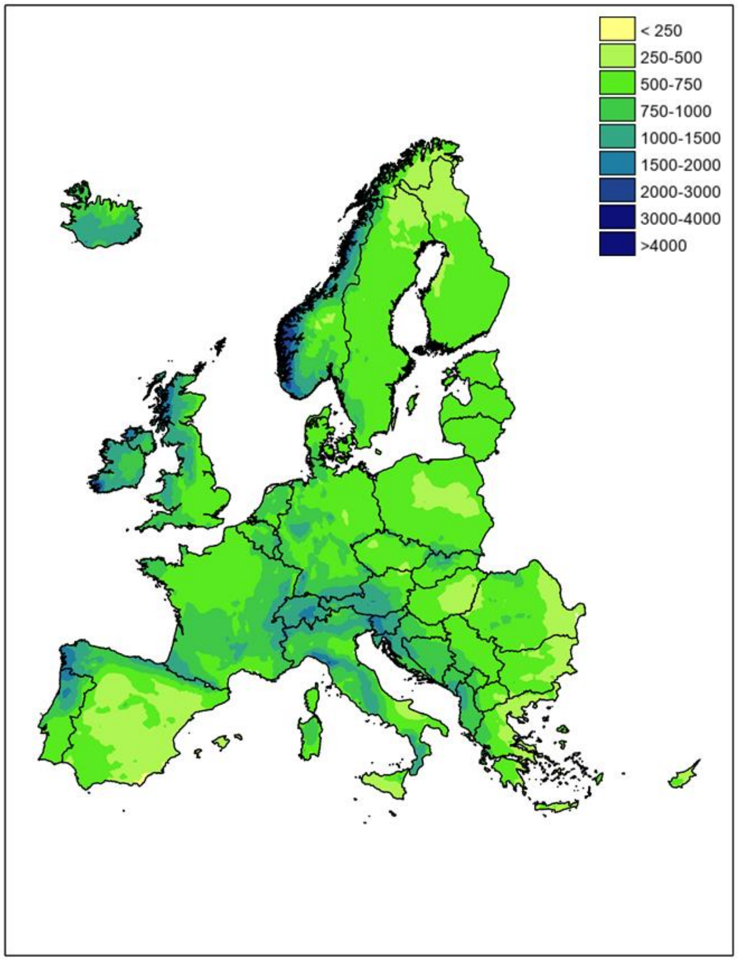
To align the applicability maps with the modelling carried out as part of D6.2, we calculate annual precipitation based on the inputs of the SoilCare IAM (sum over the monthly precipitation to obtain yearly precipitation).

Input sources for the SoilCare IAM are:

- Present-day climate data: SoilCare used E-OBS version 21.0e, at 0.1º spatial resolution and daily scale. Daily data for the ensemble mean of mean temperature, minimum temperature, maximum temperature and rainfall were collected for 1981-2010, representing the reference period used to bias-correct climate scenarios. The data source is (Cornes et al., 2018): https://surfobs.climate.copernicus.eu/dataaccess/access_eobs.php
- Climate Scenarios: To minimize bias in the project, climate scenarios at high resolution (0.1º), and already bias corrected with present-day climate (E-OBS) were used. The considered emission scenarios were RCP4.5 (closer to the average of all emission scenarios) and RCP8.5 (a more extreme emission scenario). The selected GCM-RCM combination was MPI-ES-LR + CCLM4-8-17. This means that we used the MPI-ES-LR GCM, which has a median sensitivity to climate change (Andrews et al., 2012) combined with the CCLM RCM, which appears to have less bias for temperature and rainfall in several European regions (Kotlarski et al., 2014).

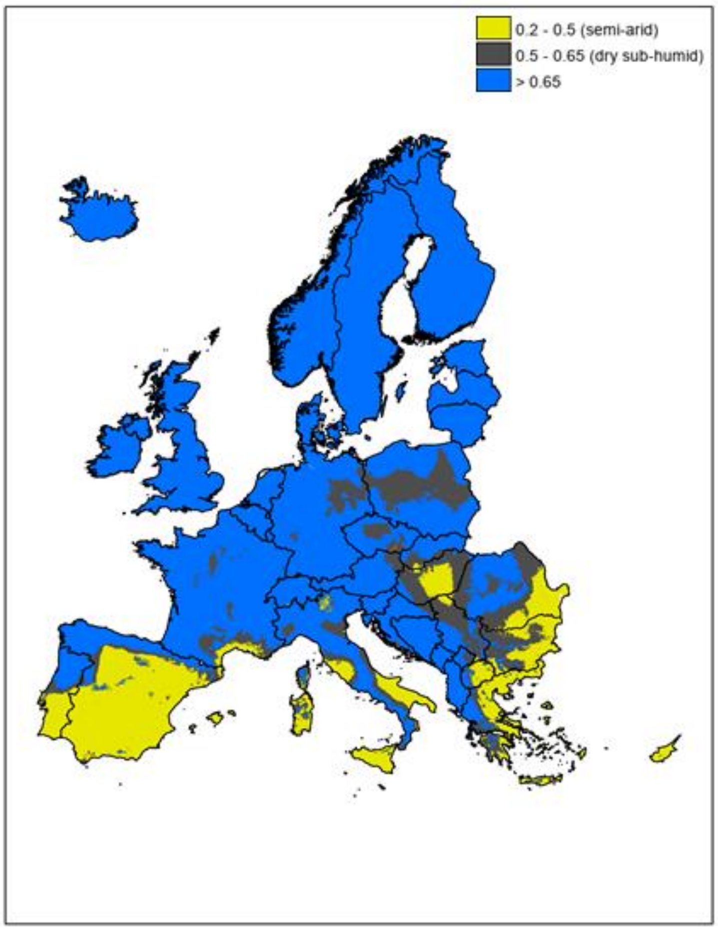
We used data from the JRC EU High Resolution and Precipitation dataset, which is already bias-corrected using E-OBS (Dosio, 2016). Data access is through: https://data.jrc.ec.europa.eu/dataset/jrc-liscoast-10011.

Precipitation - Europe

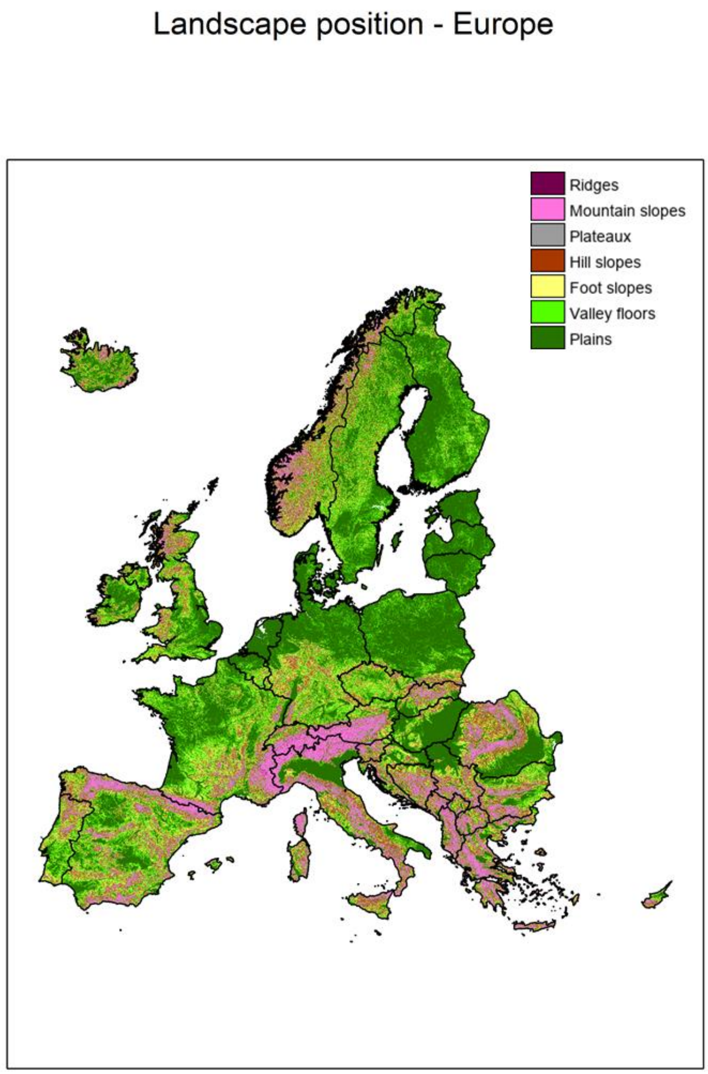


2. Aridity index

The Aridity Index (AI) is a simple but convenient numerical indicator of aridity based on long-term climatic water deficits and is calculated as the ratio precipitation / potential evapotranspiration (P/PET). The AI is a widely used measure of dryness of the climate at a given location. To align the applicability maps with the modelling carried out as part of D6.2, we calculated P and PET maps based on the inputs of the SoilCare IAM (D6.2).

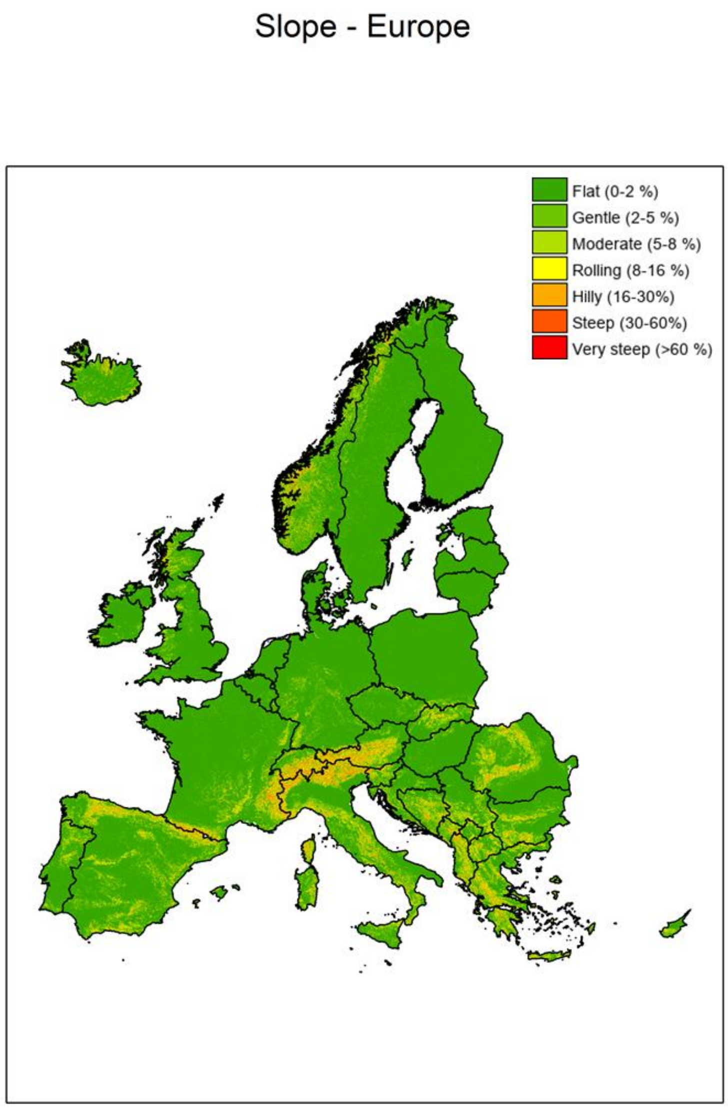


3. Landform (landscape position)



Source: Sayre et al. (2014).

4. Slope



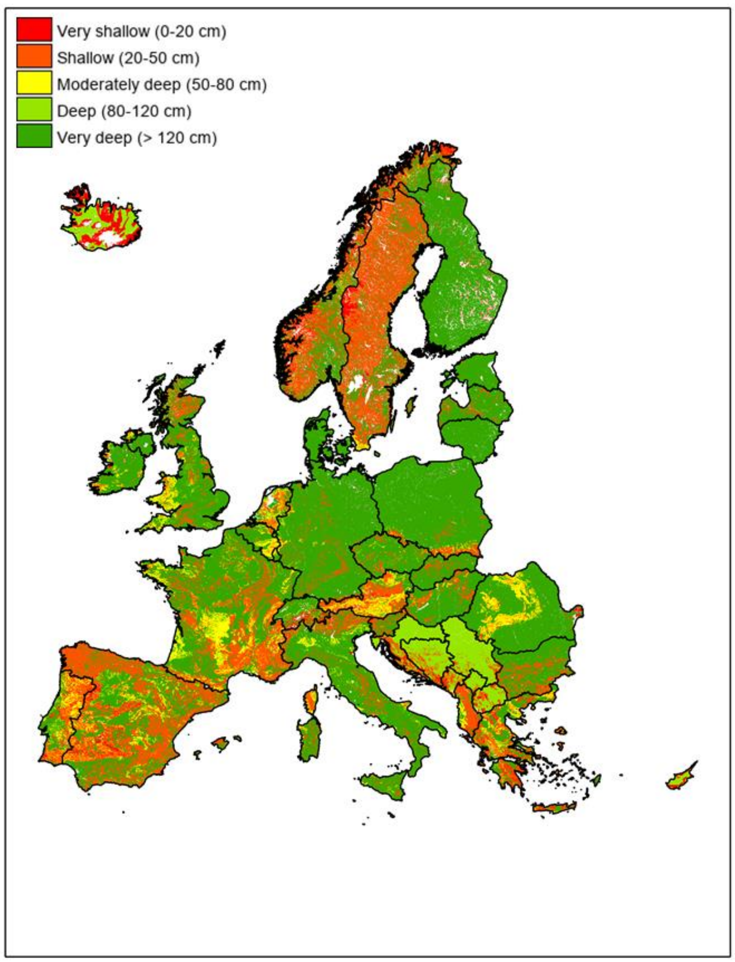
Calculated from EU-DEM 2017, European Environment Agency, https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-eu-dem

5. Soil depth

Based on minimum of the following two maps:

- Root depth limitation, from European Soil Database Maps (ESDAC) (Panagos, 2006).
- SoilGrids depth to bedrock layer (Hengl, et al., 2017).

Soil depth - Europe



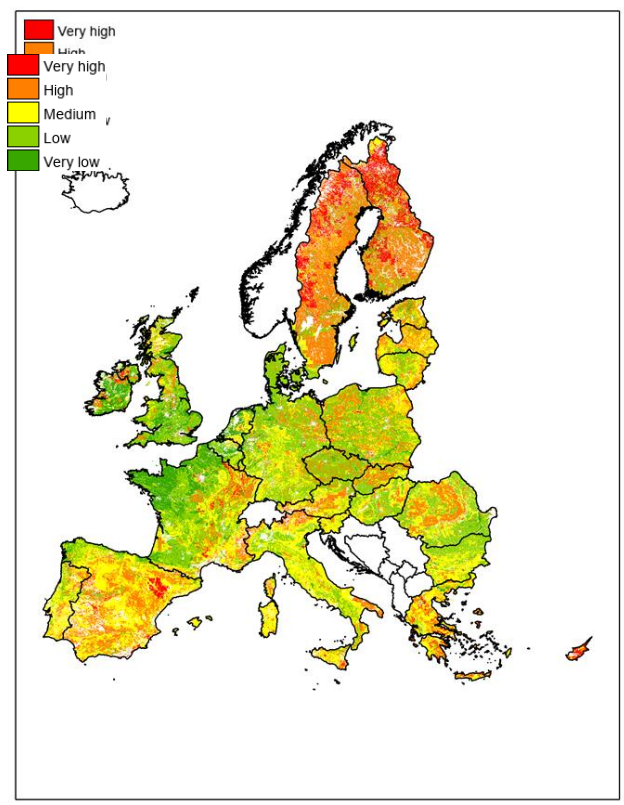
6. Soil fertility

Proxy based on 3 GIS maps that indicate the soil biomass productivity of grasslands and pasture, of croplands and of forest areas in the European Union (EU27) (Tóth et al., 2013).

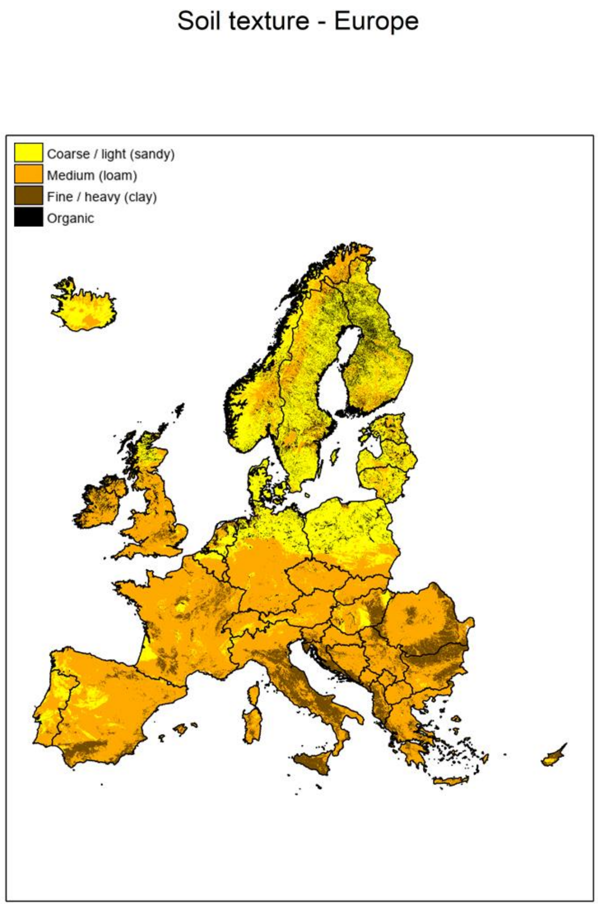
Processing:

- Downloaded the soil biomass productivity maps for grasslands, pasture, croplands and forest areas from the ESDAC database.
- Merge the 3 maps into 1 map through an overlay as the grassland, crop and forest locations don’t overlap.
- Value 0 is No, values between <0-3] are Low, <3, 6] Medium, > 6 high.
- Resampling to 100 m and alignment with the rest of the data.

Soil fertility - Europe



7. Texture

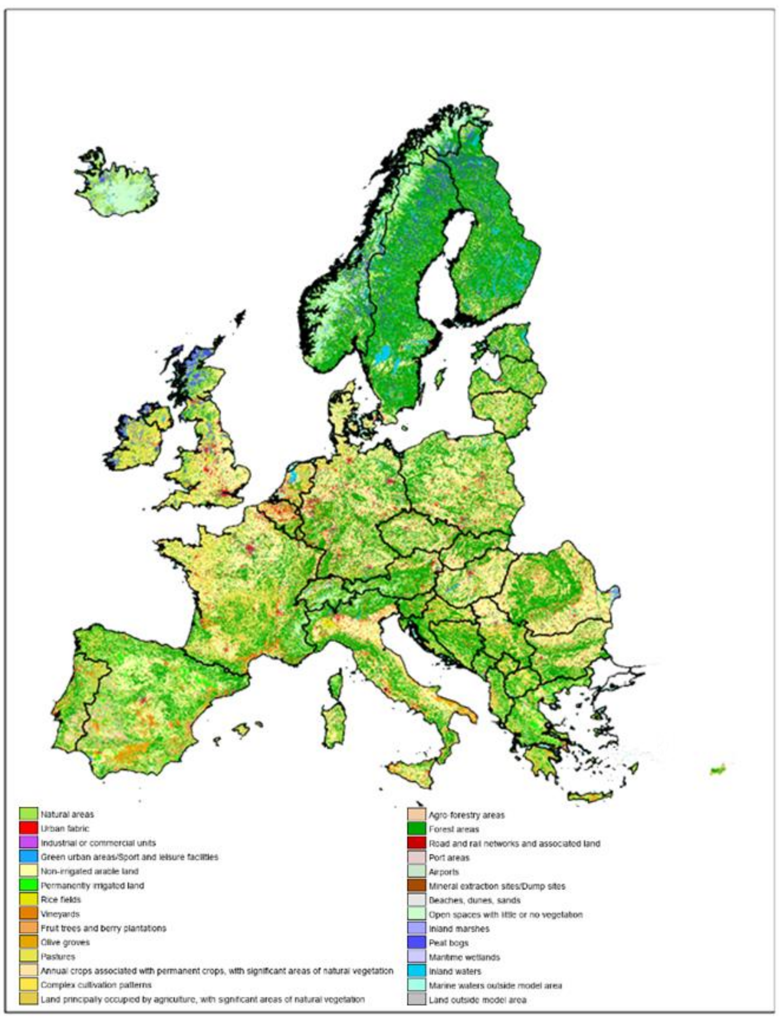


Source: Hengl, et al., (2017).

8. Land use

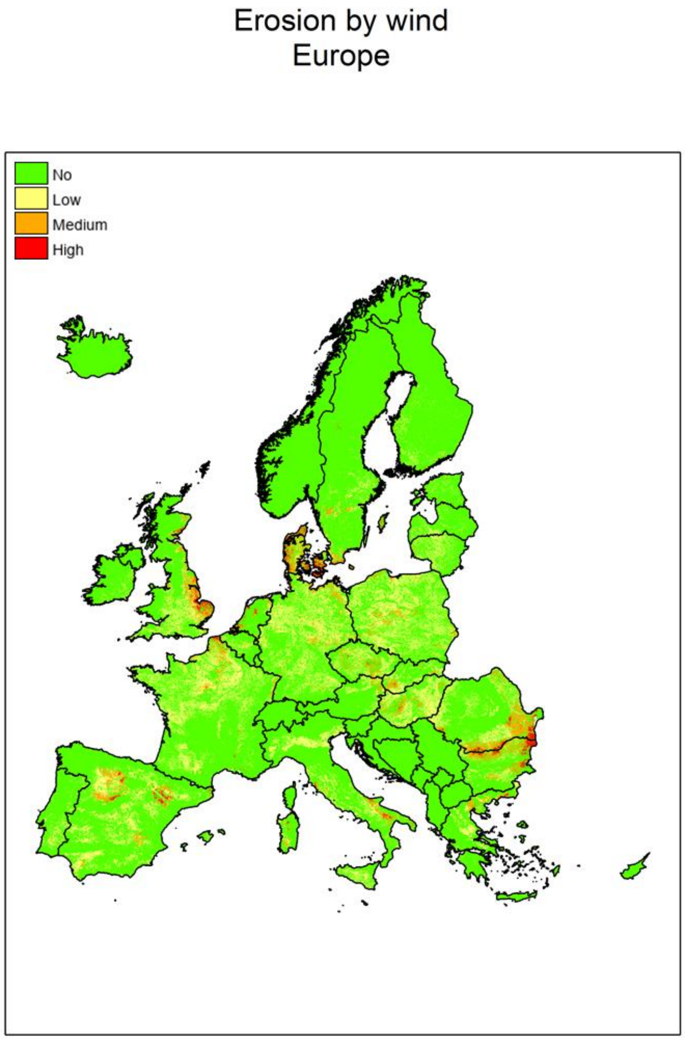
To align the applicability maps with the modelling carried out as part of D6.2, we use the SoilCare IAM land use map. The SoilCare IAM land use map is a simplified reclassification of CORINE Land Cover 2018 with agricultural areas filled in with Eurostat data (see D6.2 for more details).

Land use - Europe



9. Erosion by wind

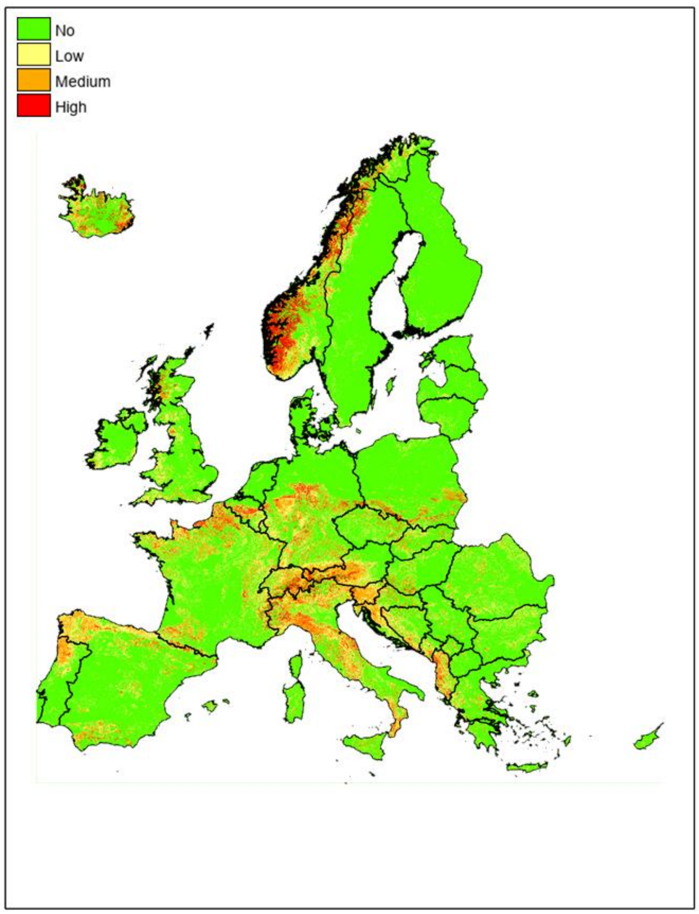
Source: Borrelli et al., (2016).



10. Erosion by water

Erosion by water is calculated by the PESERA model as incorporated in the SoilCare IAM. See for more information D6.2.

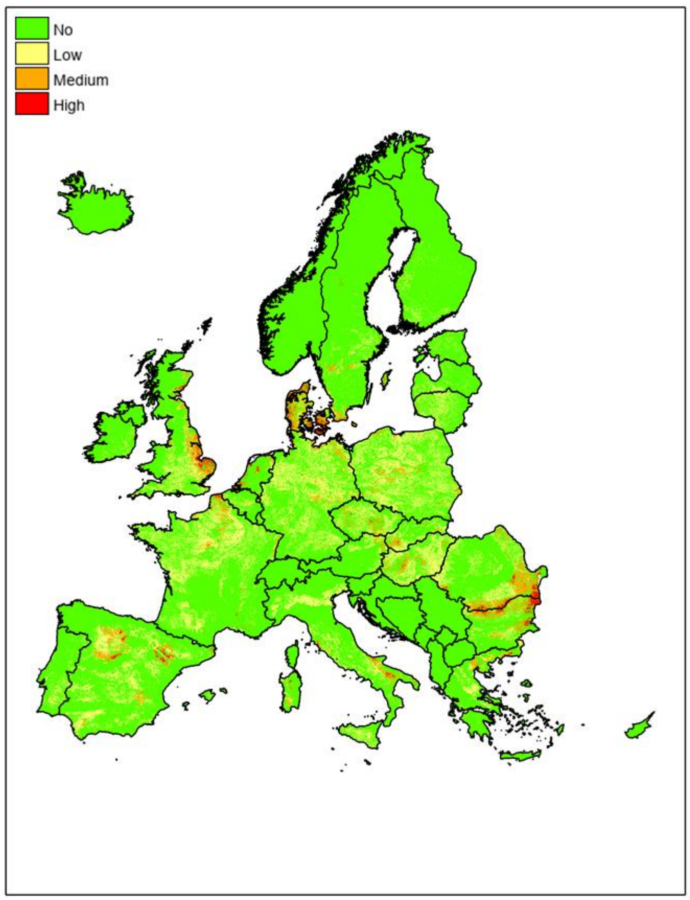
Erosion by water
Europe



11. Organic matter content

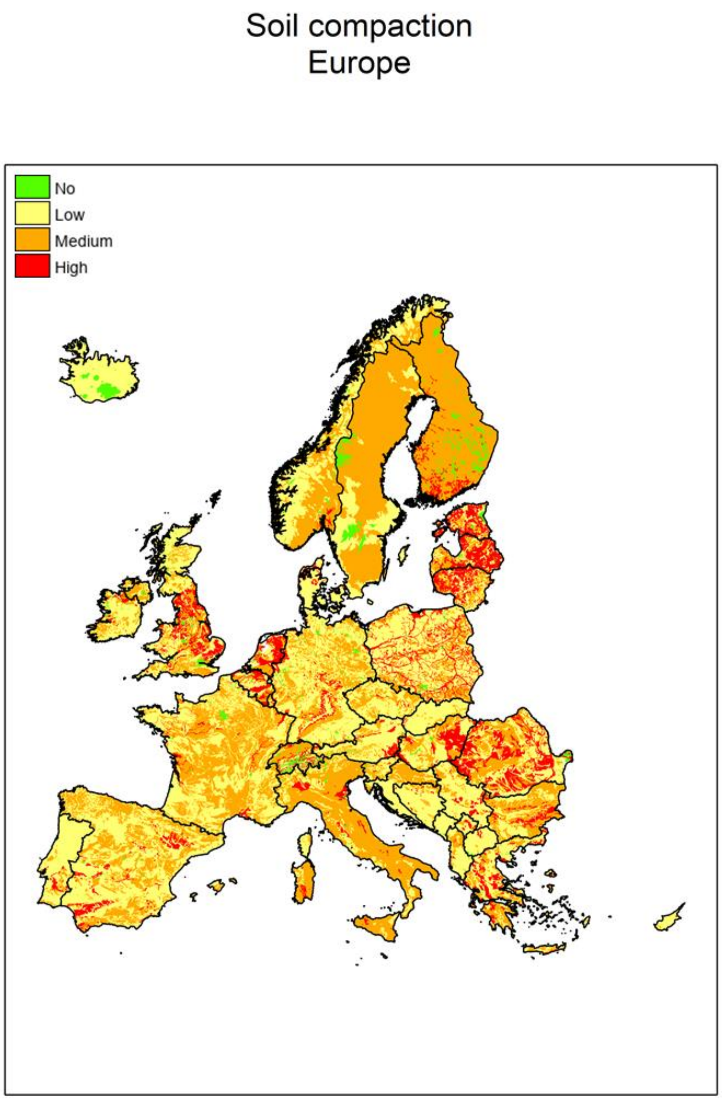
Soil organic matter is calculated by the PESERA model as incorporated in the SoilCare IAM. See for more information D6.2.

Organic matter content
Europe



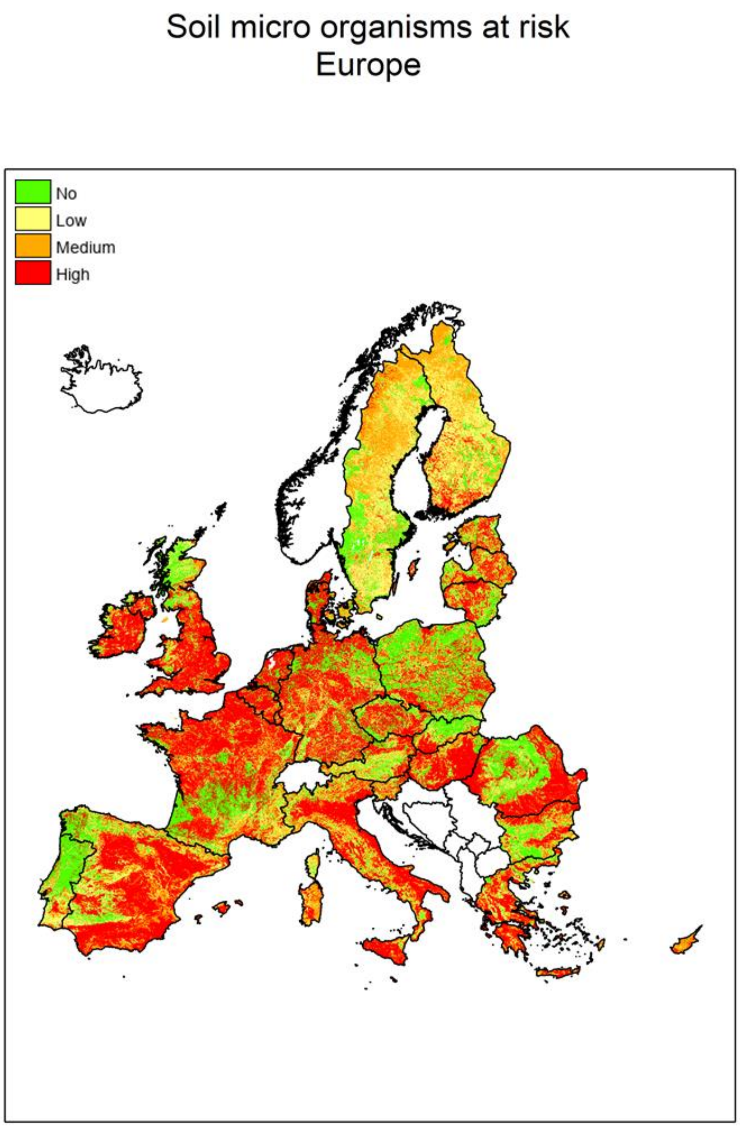
12. Soil compaction

Source: Map for Europe of Natural Susceptibility of Soils to Compaction, European Commission - Joint Research Centre, 2008; available from ESDAC.jrc.ec.europa.eu



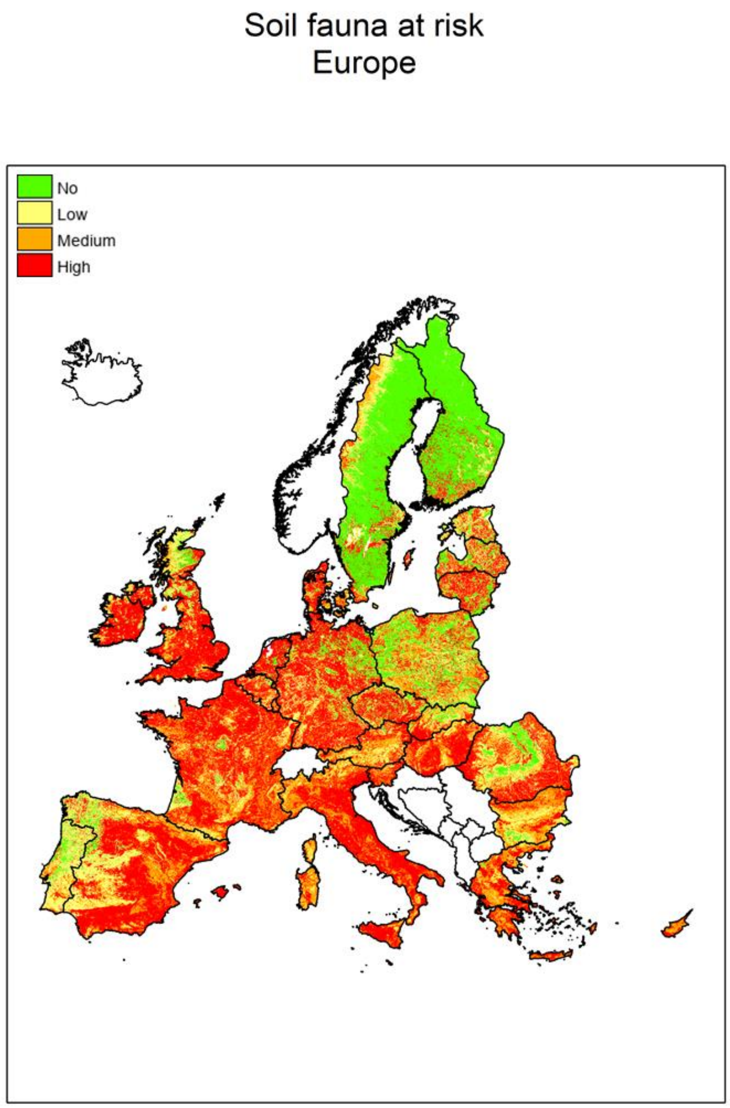
13. Soil micro-organisms at risk

Source: Orgiazzi et al, 2016. Potential threats to soil biodiversity in Europe. Set of 3 maps.



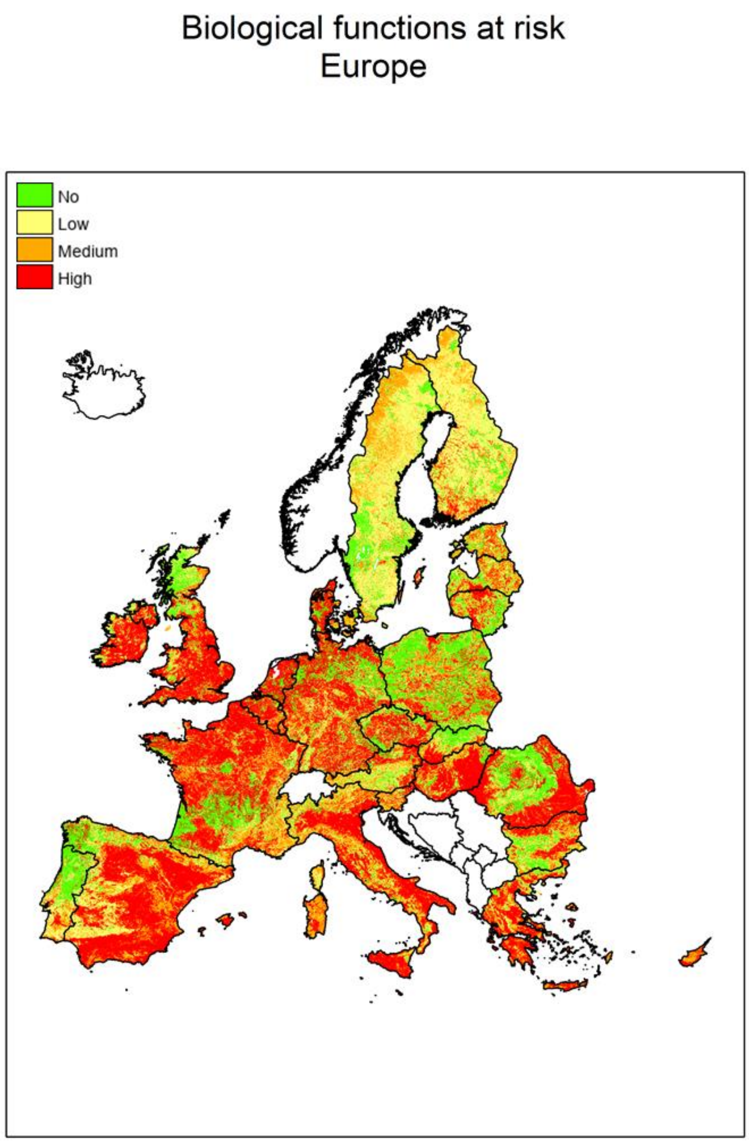
14. Soil fauna at risk

Source: Orgiazzi et al, 2016. Potential threats to soil biodiversity in Europe. Set of 3 maps.



15. Biological functions at risk

Source: Orgiazzi et al, 2016. Potential threats to soil biodiversity in Europe. Set of 3 maps.



2.3 SoilCare Integrated Assessment Model (IAM)

The SoilCare IAM has been developed as part of the SoilCare project (see D6.2) and builds on earlier Europe-wide integrated assessment models developed in amongst others the FP6 LUMOCAP and FP7 RECARE (www.recare-hub.eu) projects. The description of the IAM as given in D6.2 is included here too to ensure that the current deliverable can be understood without consulting D6.2. D6.2, however, contains more information on the results of the IAM.

2.3.1. Overview of the integrated model

The aim of the SoilCare IAM is to assess the impact of (a combination of) agricultural practices on profitability and sustainability, with a focus on soil quality. In order to do so, the SoilCare IAM consists of coupled models integrated into a policy support system. It allows the user to understand the impact of climate change and socio-economic developments on the future evolution of land use, management practices, vegetation and soil conditions. Furthermore, it provides users with the possibility to intervene in the system and assess the impact of policy, (spatial) planning and management options on profitability and sustainability indicators. The model is applied to Europe (EEA space) and includes 4 spatial levels: Europe, countries, NUTS-2 regions, local level. At local level the model operates on a grid of 100-500 m resolution. The socio-economic components operate at a yearly temporal resolution, while the hydrology and vegetation components operate on a monthly resolution. The time horizon is 2050.

An overview of the SoilCare IAM is provided in Figure 2.2. In brown the individual model components and their interactions with other model components are shown. Solid brown arrows indicate the information flow in the current time step, dashed arrows the information used as input for the next time step. The top blue box illustrates the types of scenario drivers for which the impacts can be assessed and the blue box at the bottom the types of policy-relevant information provided. The blue arrows on the left-hand side indicate where in the integrated model the scenario drivers impact.

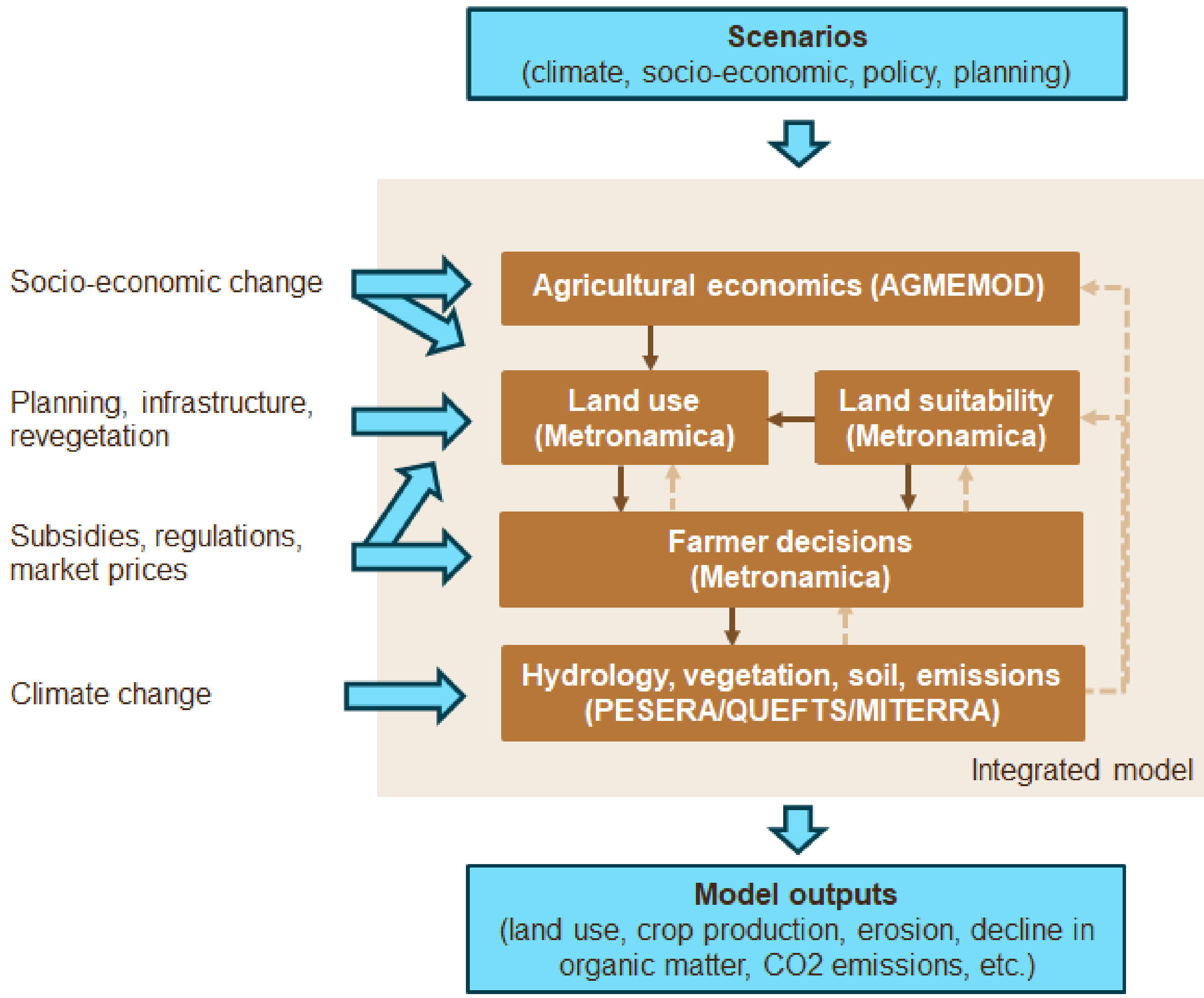


Figure 2.2: Overview of the SoilCare Integrated Assessment Model.

As can be seen from the figure, climate change and socio-economic developments are key drivers of the SoilCare IAM. Whereas climate change impacts on the hydrology and vegetation growth, the socio-economic developments result in changes in agricultural profitability and land use, which together with farmers' decisions on land management provide a land use pattern with agricultural practices at grid-cell level. The biophysical models calculate the yield and the suitability of locations for land uses, crops and agricultural practices and this information feeds into the agricultural economics, land use and farmer decisions components. In this way, temporal changes to the soil quality and other biophysical conditions have an impact on the spatial distribution of future land use and management decisions. Using information on the cost of the practice, the yield and the crop price, the IAM makes a cost-benefit (gross margin) assessment at local, cellular, level. Likewise, the inclusion of biophysical models allows the calculation of sustainability impacts of land management decisions on SOM, erosion, and emissions.

In the following section more detail is provided about the individual models that are relevant for the SICS impact calculation under current conditions as described in this report: PESERA, QUEFTS and MITERRA-Europe. More information on the SoilCare Integrated Assessment Model including its additional components, an overview of all drivers and indicators and its ability for policy support is provided in D6.2: Report on the potential for applying soil-improving CS across Europe.

2.3.2. PESERA

The core model simulating the biophysical processes in the SoilCare IAM is the Pan-European Soil Erosion Risk Assessment (PESERA) model. The PESERA model offers a state of the art erosion risk assessment at (multi)national scale (Kirkby et al, 2008). The model's robustness and flexibility has been demonstrated through its performance at different resolutions and across different agro-ecological zones. The model's main output are monthly maps of vegetation biomass, soil organic matter content, erosion, runoff and soil water deficit.

Model rationale and process description

A shortened technical description is given here, based on Kirkby et al. (2008), where all details can be found. PESERA is a process-based and spatially distributed model designed to estimate long-term average erosion rates by combining the effect of topography, climate and soil properties. A schematic model structure is provided in Figure 2.3. The model is built in three conceptual stages:

1. A storage threshold model to convert daily rainfall to daily total overland flow runoff.
2. A power law to estimate sediment transport from runoff and gradient. The model interprets sediment transported to the base of a hillslope as average soil loss.

3. Integration of daily rates over the frequency distribution of daily rainfalls to estimate long-term average erosion rates.

In the first step, a simple storage or bucket model is used to convert daily rainfall into daily overland flow runoff, which is estimated as the rainfall minus the threshold storage. The threshold storage depends dynamically on soil properties, vegetation cover and soil moisture status, varying over the year. The most important soil factors that determine the threshold storage beneath the vegetation-covered fraction of the surface are texture, depth (if shallow) and organic matter. Where the surface is not protected by vegetation, the susceptibility of the soil to crusting and the duration of crusting conditions generally determine a lower threshold. The final threshold is a weighted average from vegetated and bare fractions of the surface. Corrections are made for the soil water deficit, which may reduce the threshold where the soil is close to saturation.

Transpiration is used to drive a generic plant growth model for biomass, constrained as necessary by land use decisions, primarily on a monthly time step. Leaf fall, with corrections for cropping, grazing, etc., also drives a simple model for soil organic matter.

Precipitation is divided into daily storm events, expressed as a frequency distribution. The distribution of daily rainfall totals has been fitted to a Gamma distribution for each month. The rainfall distribution, reflected by the coefficient of variation of rainfall per rain day is given for each month of the simulation period and may be adapted for (future) climate change scenarios. Daily precipitation drives infiltration, excess overland flow and soil erosion, and monthly precipitation, driving saturation levels in the soil. Infiltration excess overland flow runoff is estimated from storm rainfall and soil moisture. Sediment transport is then estimated using a power law approach driven by erodibility, gradient and runoff discharge. Estimates of sediment transport are based on infiltration excess overland flow discharge. In the PESERA model, sediment transport is interpreted as the mean sediment yield delivered to stream channels and does not include downstream routing within the channel network. The PESERA model includes three terms:

- Soil erodibility, which is derived from soil classification data, primarily interpreted as texture (Le Bissonnais et al., 2002).

- Local relief, which is derived from DEM data as the standard deviation of elevation within a defined radius around each point.

- An estimate of accumulated runoff, which is derived from a biophysical model that combines the frequency of daily storm sizes with an assessment of runoff thresholds based on seasonal water deficit and vegetation growth.

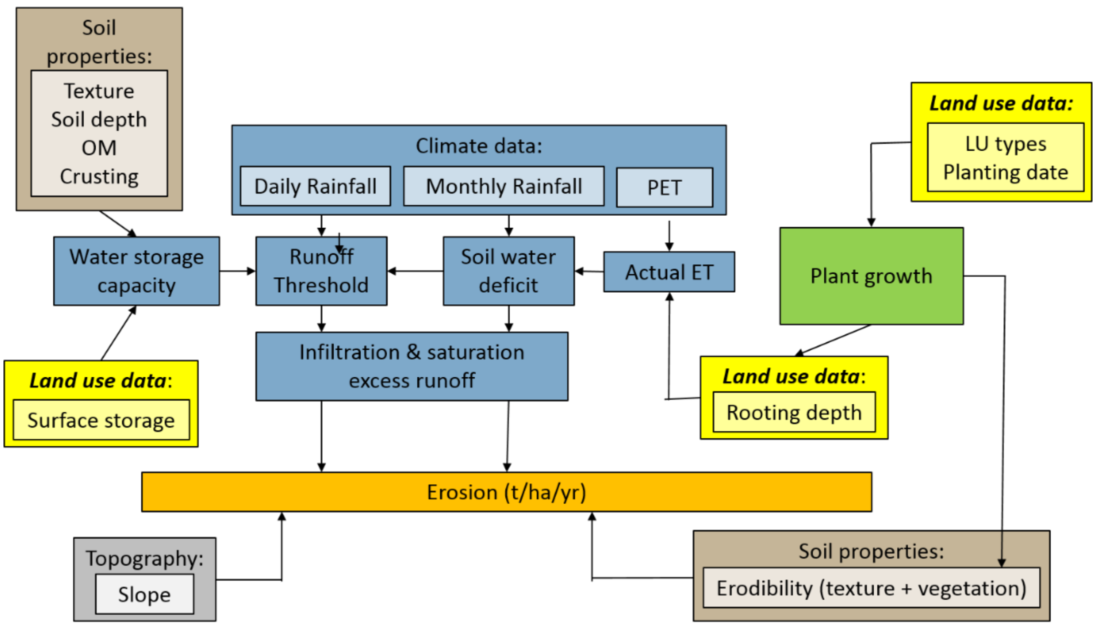


Figure 2.3: Schematic overview of processes in the biophysical model component

Finally, to obtain long-term estimates of soil erosion these estimates must then be scaled up by integrating over time. This process of scaling up has two stages; first from momentary to event-integrated dependence, and secondly from events to long-term averages via the frequency distribution.

The role of vegetation and soil organic matter can modify the infiltration rates through changes in soil structure and/or the development over time of surface or near-surface crusting. Three models are coupled to provide the dynamics of these responses: (i) an 'at-a-point' hydrological balance, which partitions precipitation between evapo-transpiration, overland flow, subsurface flow and changes in soil moisture; (ii) a vegetation growth model, which budgets living biomass and organic matter subject to the constraints of land use and cultivation choices; and (iii) a soil model, which estimates the required hydrological variables from moisture, vegetation and seasonal rainfall history.

Biomass output from the PESERA model can be directly used to estimate the vegetation biomass of a pixel of a given land cover category. Its carbon content can be assessed through a carbon factor. For agricultural crops, water-limited yield can be estimated by multiplying biomass with a harvest index.

2.3.3. Dyna-QUEFTS

Whereas the vegetation model component in PESERA simulates the impact of water availability, specific consideration is also given to nutrient limitations by building in Dyna-QUEFTS, a spatially-explicit and dynamic version of the QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) model (Janssen et al., 1990). Nutrient limitations are important in many locations across Europe. Moreover, land management systems often include higher use of inputs, which helps generate higher yields which would not be captured if nutrient availability and uptake are not explicitly considered.

QUEFTS was initially developed for quantitative evaluation of the native fertility of tropical soils, using calculated yields of unfertilized maize as a yardstick. In the past decade, QUEFTS has been adapted to improve its global applicability, including in temperate zones (Sattari et al., 2014). It can also consider nutrients applied by the land user, and the model has been successfully parameterised to cover other crops next to maize (Sattari et al., 2014).

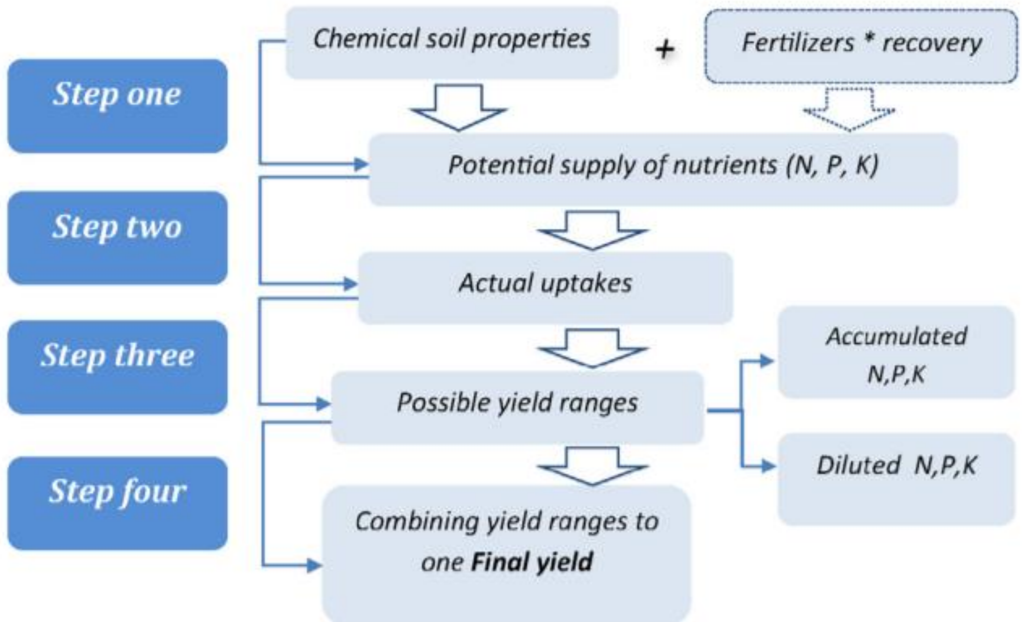


Figure 2.4: The four steps in the simulation procedure of QUEFTS (Source: Sattari et al., 2014).

The procedure consists of four successive steps (Figure 2.4). First, based on fertilization trials, the potential supplies of nitrogen, phosphorus and potassium are calculated, applying relationships between chemical properties of the 0-20 cm soil layer and the maximum quantity of those nutrients that can be taken up by a crop, if no other nutrients and no other growth factors are yield-limiting. In the second step the actual uptake of each nutrient is calculated as a function of the potential supply of that nutrient, taking into account the potential supplies of the other two nutrients. Step 3 comprises the establishment of three yield ranges, as depending on the actual uptakes of nitrogen, phosphorus, and potassium, respectively. Next, these yield ranges are combined in pairs, and the yields estimated for pairs of nutrients are averaged to obtain an ultimate yield estimate (Step 4).

In the Dyna-QUEFTS model the above-mentioned four steps are calculated for a grid map instead of a single point. Furthermore, N supply is through the SOM map of the PESERA model, and in a fifth step of the model P and K supply in the soil is updated due to nutrient additions and subtractions in the respective time step.

Dyna-QUEFTS uses maps on soil nutrient data as input, together with temperature, pH, maximum yield and fertilizer applications and recovery fractions. It outputs nutrient-limited crop yield. Details of the Dyna-QUEFTS model can be found in (Fleskens et al., 2021). Here, it has been further adapted by considering further crops (wheat, rice, pulses, sugarbeet, potato and oilseeds) and nutrient cycling processes (atmospheric N and K deposition and N fixation).

The final yield calculated in the biophysical models is assumed as the minimum of water-limited (PESERA) and nutrient-limited (QUEFTS) yield.

2.3.4. MITERRA-Europe

MITERRA-Europe is a deterministic emission and nutrient flow model, which calculates greenhouse gas (CO_2, CH_4 and N_2O) emissions, nitrogen emissions (N_2O, NH_3, NO_x and NO_3), N and P flows, soil organic carbon stock changes and soil erosion on annual basis, using emission factors and leaching fractions. The model was developed to assess the effects and interactions of policies and measures in agriculture on N losses on a NUTS-2 (Nomenclature of Territorial Units for Statistics) level in the EU-28 (Velthof et al., 2009; de Vries et al., 2011). The MITERRA-Europe model was originally based on the models CAPRI (Common Agricultural Policy Regionalised Impact), and GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies), and was supplemented with a N leaching module, a soil carbon module, and a module for greenhouse gas mitigation measures. In addition, soil erosion by water is calculated following the Revised Universal Soil Loss Equation (RUSLE) approach (Panagos et al., 2015).

Input data consist of activity data (e.g., livestock numbers and crop areas and yield from CAPRI, Eurostat and FAOSTAT), soil data (LUCAS), climate data (WorldClim), GHG emission factors (IPCC, UNFCCC), and NH_3 emission factors, excretion factors and manure management system data (GAINS, UNFCCC). The model includes measures to simulate carbon sequestration and mitigation of GHG and NH_3 emissions and NO_3 leaching. For soil carbon, the calculation rules of the well-known soil carbon model RothC are used (Merante et al., 2014). RothC (version 26.3; Coleman et al., 1997; Coleman and Jenkinson, 2014) is a model for the turnover of organic carbon in non-waterlogged soils that takes effects of soil type, temperature, moisture content and plant cover on the turnover process into account. It uses a monthly time step to calculate total organic carbon on a year-to-century timescale. In the RothC model, SOC is split into four active compartments and a small amount of inert organic matter. The four active compartments are decomposable plant material, resistant plant material, microbial biomass and humified organic matter. Each compartment decomposes by a first-order process with its own characteristic rate. The MITERRA-Europe model is described in more detail in Velthof et al. (2009) and Lesschen et al. (2011) and the most recent input data is described in Duan et al. (2021).

As part of this deliverable, MITERRA is used to calculate information on the following indicators: soil nitrogen balance, nitrous oxide (N2O) emission, ammonia (NH3) emission, N leaching and runoff.

3. SICS Potential Index results

This chapter provides the results of the SICS Potential Index. It is divided into two sections.

The first section (3.1) includes the results of the SICS that have been tested in the different study sites and is based on the Europe-wide maps described under 2.1 and the questionnaire results provided by the study site partners (see Annex A1 for the questionnaire results).

The second section (3.2) provides results of the SICS that have been selected for modelling at the European scale. For these the full SICS Potential Index is calculated and hence these results include the impact assessment modelling.

3.1 SICS Potential Index results per Study Site based on applicability and relevance

In the following sections results of the SICS Potential Index are presented for those SICS that have been tested in the study sites. As discussed in the methodology section, for these SICS, we assess the applicability, the relevance and the combined applicability/relevance. The latter shows the applicability of SICS in areas where it is relevant to implement them. Figure 3.1 shows an overview of this process as a subset of the full SICS Potential Index approach as presented in Figure 2.1 in Section 2.

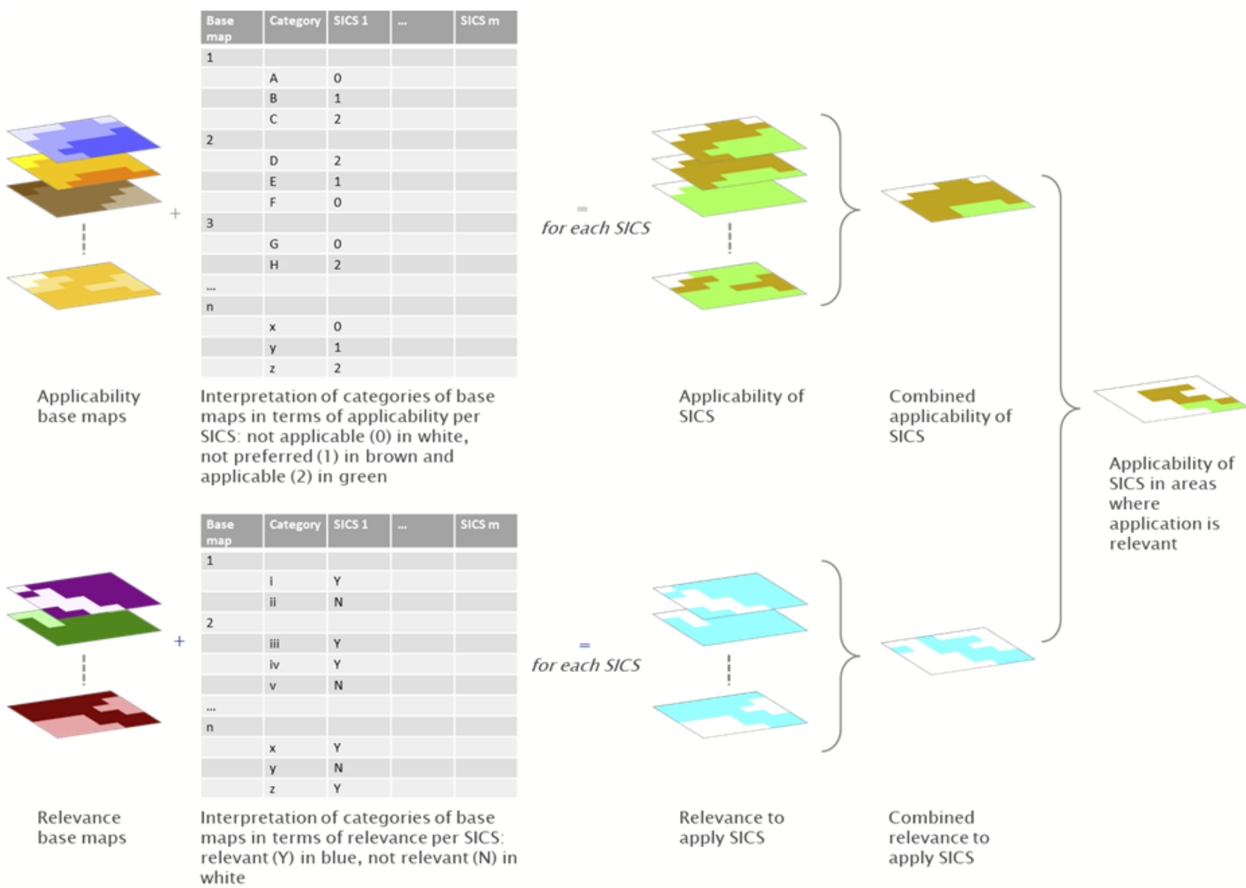


Figure 3.1. Process to assess the applicability, the relevance and combined applicability/relevance of SICS

On the next pages, for each SICS we start by providing a brief description, followed by the factors influencing their application and adoption, a brief overview of the sources used and where further information can be obtained, and finally the set of maps. The full analysis for each SICS is available through the slide decks and all settings for the interpretation of the applicability and the relevance maps are provided through the SoilCare Interactive Mapping Tool (IMT). The table below indicates what relevance factors were selected by study site partners and their stakeholders for each of the SICS. In this report only the main factor is used. In the SoilCare IMT all selected individual factors are applied as well as a combination of all selected relevance factors per SICS.

Table 3.1: Relevance factors per SICS. Factors with a bold ***X*** *are found most relevant for SICS application.*

	Water erosion	Water erosion	Soil compaction	Organic matter content	Soil micro-organisms at	Soil fauna at risk	Biological functions at risk
Conservation agriculture	**X**	**X**	**X**	**X**			**X**
Direct seeding	**X**	**X**		X		**X**	
Cover crops in winter	X	X	X	**X**			X
Wood chips		X	X	**X**			
No till and cover crop	X	X	**X**	**X**			X
Crop rotation				**X**			
Cover crop, liming, manure				**X**			
Minimum tillage and plant nutrition		**X**	**X**	**X**			
Cover crops in orchards	X	**X**	X	X			X
Early sowing of wheat		**X**	X	**X**			
No tillage		**X**	X	X			
Subsoil loosening			**X**	**X**			
Subsoiling			**X**				
Green manure				**X**	X	X	X
Deep-rooting grass-ley cultivars		X	**X**	X			
No till to alleviate compaction		X	**X**				
Organic rice in rotation				**X**			
Succession system				**X**	X		
Organic fertilisation				**X**	X		X
Grass verges		X	**X**	X			
Underfoot fertilisation after CULTAN				**X**			
Intercropping and minimum tillage		**X**	X	**X**	X	X	X
Cover crops in spring	X	X	X	**X**		X	

3.1.1. Conservation agriculture

Conservation agriculture is a farming practice that promotes minimum soil disturbance, maintenance of a permanent soil cover, and diversification of plant species. In the German Study Site reduced tillage was tested to determine whether it could reduce soil erosion and soil fertility loss. In addition, cover crops were used to enhance this effect and potentially suppress weeds, in order to avoid glyphosate use, which is commonly used for weed suppression in no-till systems.

Additional application and adoption factors:

Even soils with (very) low fertility can be improved by conservation agriculture, but inputs (e.g. compost) may be necessary at the start to establish a system with good cover crops.

The technique requires a high level of expertise regarding the suitable management of crop rotation and cover crops (including the selection of crops to use), to prevent problems with weeds and soil compaction. Correct application is critical for the SICS to be effective.

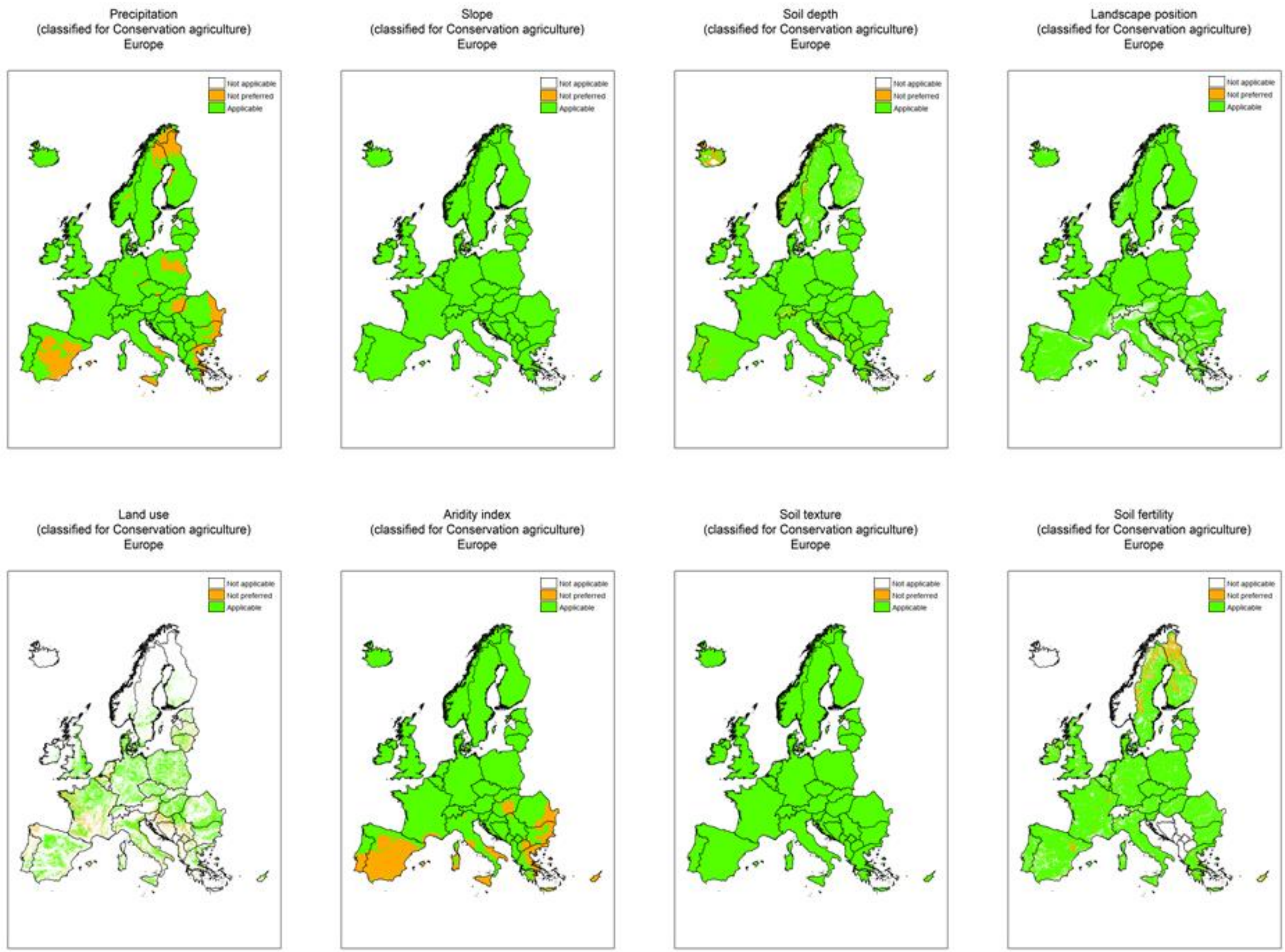
Financial incentives are likely required to facilitate adoption of direct seeding. Financial benefits are expected to outweigh the costs, but only after a few years. It takes time before the soil benefits will become visible and farmers gain experience in the technique. Impacts on erosion reduction will be visible from the start of the practice. Once a conservation agriculture system is established it has much lower labour costs because of fewer tillage operations.

Factors encouraging the adoption of this SICS include reduced fuel consumption and reduced workload, the ability to cultivate heavy soils, reduced need for fertilisers, reduced erosion, biodiversity enhancement and societal demand for sustainable products. Furthermore, it was noted that field demonstrations help in the uptake to the SICS. Key socio-economic aspects listed as important for the adoption of the SICS further include: financial capability of the farmer to implement the technique without support, availability of subsidies, willingness of the farmer, political willingness, awareness and understanding of the technique, application of the technique by peers, proven effectiveness of the technique, and the education level of the farmer (or person implementing the technique). Furthermore, it was noted that having a successor and legislative requirements would facilitate the adoption as well.

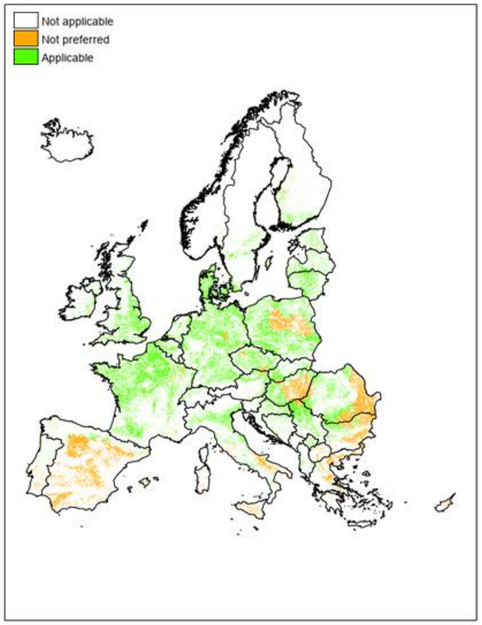
Barriers listed to prevent the adoption include the possible yield reduction, cost of seeds for cover crops, insufficient knowledge about the practice and the complexity of the practice, potential increased need for pesticides/new machines if no till is applied without cover crops.

Sources and more information:

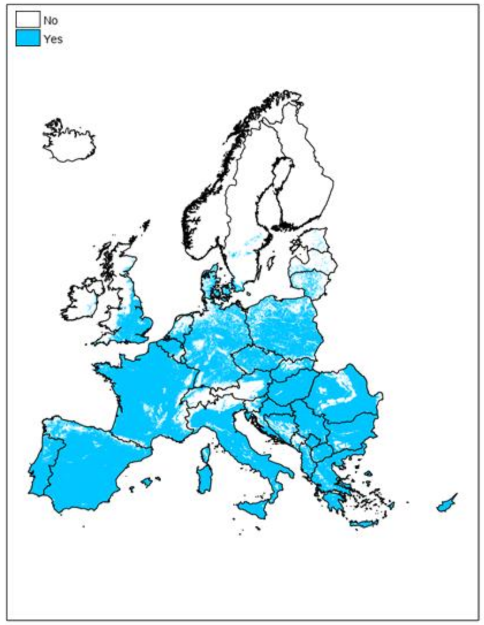
The WP4 & WP6 questionnaires, the fact sheet Germany: Effects of cover crops and glyphosate on soil organisms, and deliverables D5.3: Report on monitoring results and analysis, and D7.2: Report on the selection of good policy alternatives at EU and study site level.


Precipitation
(classified for Conservation agriculture)
Europe
Slope
(classified for Conservation agriculture)
Europe
Soil depth
(classified for Conservation agriculture)
Europe
Landscape position
(classified for Conservation agriculture)
Europe
Land use
(classified for Conservation agriculture)
Europe
Aridity index
(classified for Conservation agriculture)
Europe
Soil texture
(classified for Conservation agriculture)
Europe
Soil fertility
(classified for Conservation agriculture)
Europe
Not applicable
Not preferred
Applicable

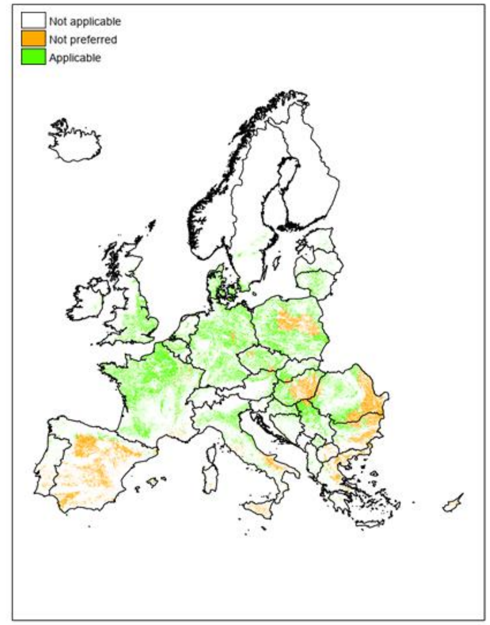
Overall applicability
Conservation agriculture
Europe



Relevance
Conservation agriculture
Europe



Combined
Conservation agriculture
Europe



3.1.2. Direct seeding

Direct seeding is when crops are sown through the residue of the previous crop, in the German study site this was the case for the cover crop. There is no tillage for seedbed preparation. This practice provides protection from erosion and nutrient run-off and helps retain moisture for the new crop as water savings are expected due to reduced evaporation.

Additional application and adoption factors:

Direct seeding can only be successful under the right conditions. Before sowing (July/August) it needs to be dry, after seeding (July-September), some minor rainfall is very important for field emergence of the cover crop. Summer rain uncertainty imposes a risk for using this SICS as it may be necessary to re-seed and seeds are expensive. This risk might hamper the adoption of direct seeding.

Because direct seeding is soil water saving it can be especially beneficial in dry areas. Climate change impacts might make this practice more widely applicable.

In clay soils direct seeding is more difficult. In terms of equipment a direct seeding machine is necessary. This could be rented from or shared with other farmers to share costs and facilitate the uptake of the SICS.

The technique requires a high level of expertise and correct application is critical for the SICS to be effective.

Applying this SICS, occurrence of weeds can be a problem. Up till now, direct seeding depends on reliable and non-selective herbicides. However, there are some pioneers developing management examples of herbicide-free direct seeding cropping systems.

Financial benefits are expected to outweigh the costs, but only after a few years. An established system has much lower costs and can provide the same yield levels as a cropping system in which seeding is done with seedbed preparation. Labour costs are greatly reduced with direct seeding.

Key socio-economic aspects listed as important for the adoption of the SICS include: financial capability of the farmer to implement the technique without support, availability of subsidies, willingness of the farmer, political willingness, awareness and understanding of the technique, application of the technique by peers, proven effectiveness of the technique, and the education level of the farmer (or person implementing the technique). Furthermore, it was noted that having a successor and legislative requirements would facilitate the adoption as well. Although the technique can be applied to any farm size, it might be easier for larger farms to adopt it because of their increased financial capability and economies of scale.

Sources and more information:

The WP4 & WP6 questionnaires and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Direct seeding)
Europe

Slope
(classified for Direct seeding)
Europe

Soil depth
(classified for Direct seeding)
Europe

Landscape position
(classified for Direct seeding)
Europe

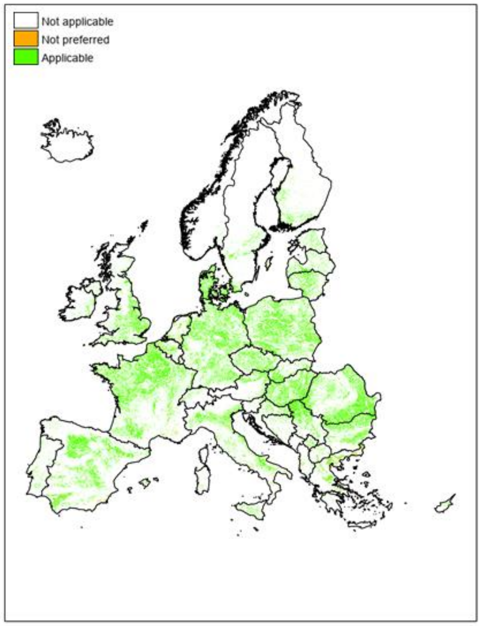
Land use
(classified for Direct seeding)
Europe

Aridity index
(classified for Direct seeding)
Europe

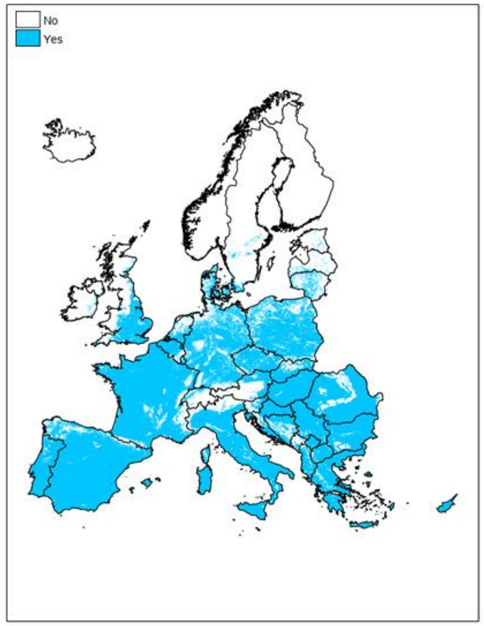
Soil texture
(classified for Direct seeding)
Europe

Soil fertility
(classified for Direct seeding)
Europe

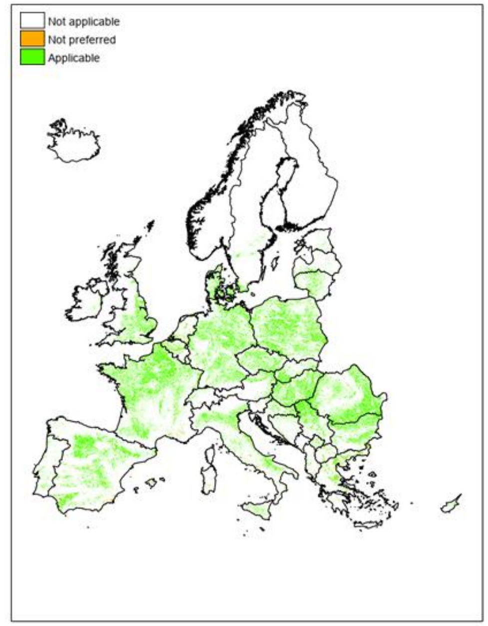
Overall applicability
Direct seeding
Europe



Relevance
Direct seeding
Europe



Combined
Direct seeding
Europe



3.1.3. Cover crops in winter

Cover crops cover the soil in winter when crops used for harvest are not in the soil, thus providing a cover to reduce erosion and increase soil fertility. In the German study site they also had the aim to control weeds in a no tillage system in order to avoid the need for herbicide use.

Additional application and adoption factors:

For winter cover crops, frost is important to kill the cover crop, otherwise herbicide is necessary to do this, in order to avoid competition with the main crop in spring. A roller crimper could replace herbicides.

Factors encouraging the adoption of this SICS include reduced need for fertilisers and biodiversity enhancement. Key socio-economic aspects listed as important for the adoption of the SICS include: financial capability of the farmer to implement the technique without support, availability of subsidies, willingness of the farmer, political willingness, awareness and understanding of the technique, application of the technique by peers, proven effectiveness of the technique, and the education level of the farmer (or person implementing the technique). Furthermore, it was noted the having a successor and legislative requirements would facilitate the adoption as well.

Barriers listed to prevent the adoption include the cost of seeds, insufficient knowledge about the practice and the complexity of the practice.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Germany: Effects of cover crops and glyphosate on soil organisms, and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Cover crops in winter)
Europe

Slope
(classified for Cover crops in winter)
Europe

Soil depth
(classified for Cover crops in winter)
Europe

Landscape position
(classified for Cover crops in winter)
Europe

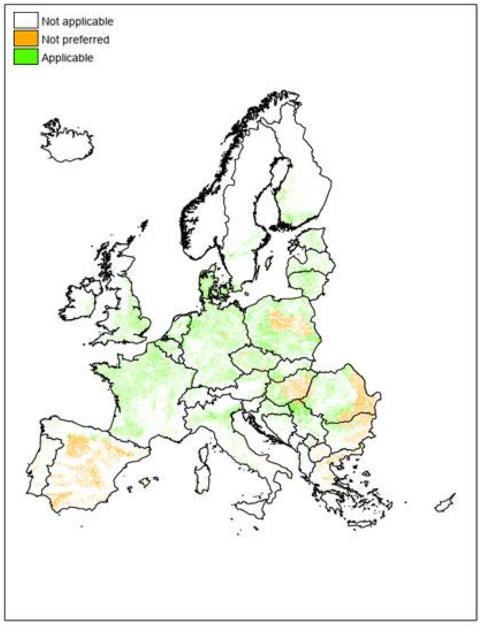
Land use
(classified for Cover crops in winter)
Europe

Aridity index
(classified for Cover crops in winter)
Europe

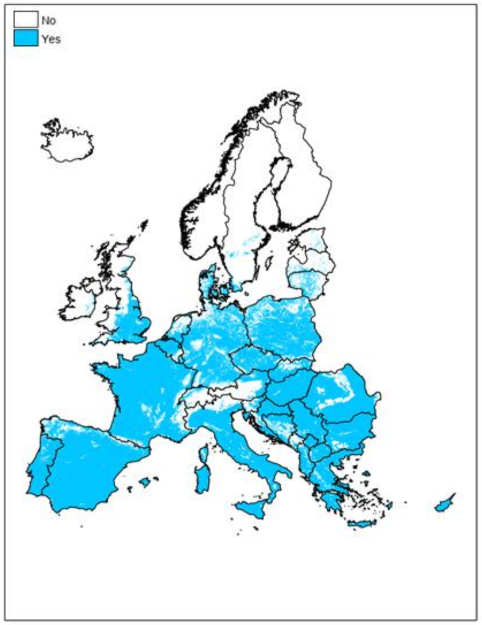
Soil texture
(classified for Cover crops in winter)
Europe

Soil fertility
(classified for Cover crops in winter)
Europe

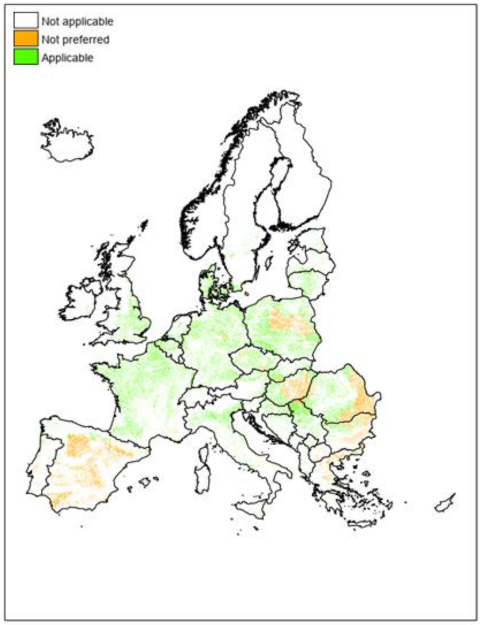
Overall applicability
Cover crops in winter
Europe



Relevance
Cover crops in winter
Europe



Combined
Cover crops in winter
Europe



3.1.4. Woodchips

Wood chips are applied to alleviate soil-health problems such as low soil organic carbon content, soil erosion and compaction. Compared to other organic amendments such as pig manure, wood chips provide less nutrients and hence can be useful to apply in areas with limitations to nutrient inputs. This approach was investigated in the Belgian study site. The wood chips were incorporated into the soil.

Additional application and adoption factors:

An important success factor for this SICS is the availability of wood chips. In countries with excess nutrients and legislation to limit a further increase, wood chips can provide a good alternative to other amendments to increase soil organic carbon due to their low N and P content.

Main barriers are inconsistent legislation which prevents farmers from acting in the long-term or taking up new measures, insufficient awareness of the advantages of these amendments amongst farmers and the costs of implementation. (Financial) support and incentives from policy are hence needed for a successful implementation.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Belgium: Organic soil amendments for improving soil quality and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Wood chips)
Europe

Slope
(classified for Wood chips)
Europe

Soil depth
(classified for Wood chips)
Europe

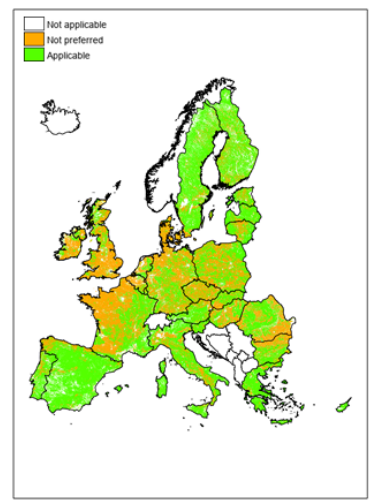
Landscape position
(classified for Wood chips)
Europe

Land use
(classified for Wood chips)
Europe

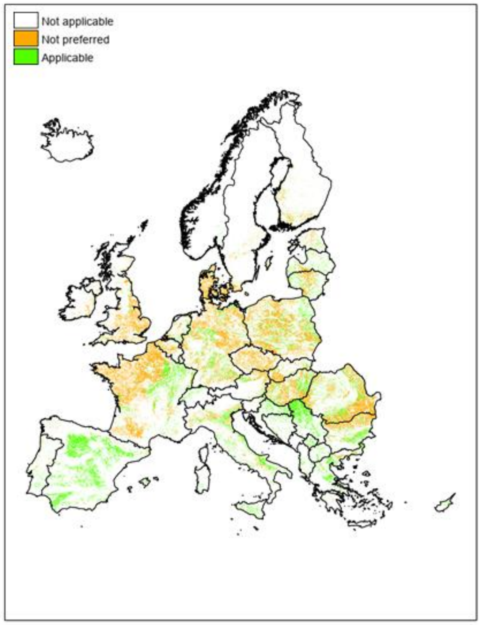
Aridity index
(classified for Wood chips)
Europe

Soil texture
(classified for Wood chips)
Europe

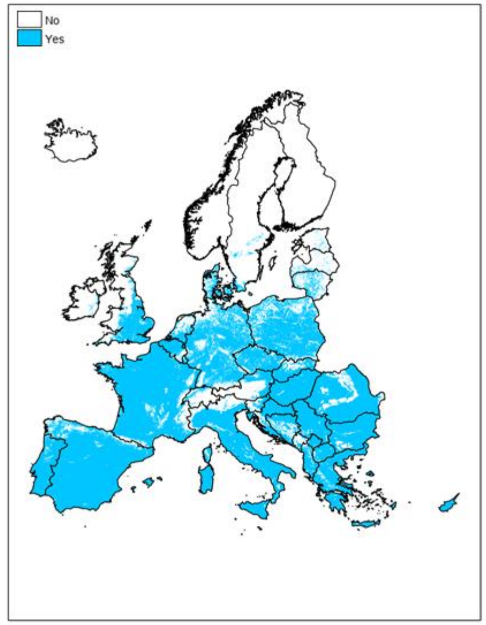
Soil fertility
(classified for Wood chips)
Europe



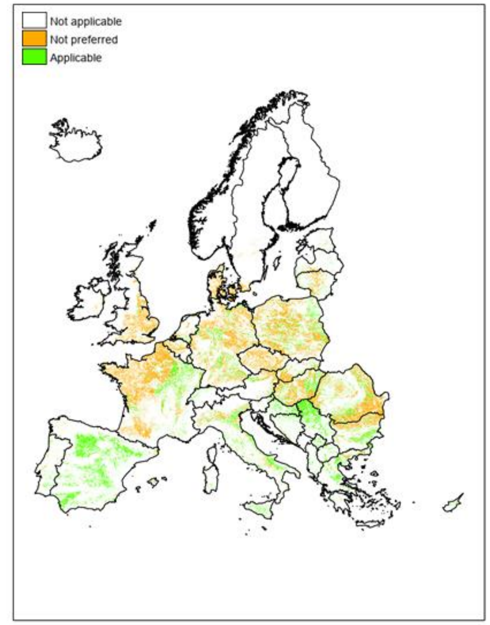
Overall applicability
Wood chips
Europe



Relevance
Wood chips
Europe



Combined
Wood chips
Europe



3.1.5. No till and cover crops

This SICS includes the introduction of cover crops and no tillage and was investigated in the Italian study site. By avoiding tillage, the soil has less pressure on the surface from heavy machinery, preventing further compaction. Over time the soil is expected to de-compress, which can be facilitated with deep-rooting crops, such as deep-rooting radish that has the ability to create a structure deeper into the soil through root channels potentially helping to alleviate compaction, allowing air and moisture in, whilst adding organic matter into the soil. It could also help to sequester carbon below the plough layer (approx. 30 cm) and the cover in winter helps to mitigate soil erosion. The SICS can also result in an increase of nutrient efficiency through reduction of leaching.

Additional application and adoption factors:

It is important to use appropriate species for winter cover crops. The germination of tillage radish varies depending on soil type and tillage radish appears to need herbicide to terminate it before the main crop is sown. Challenges identified surrounding no-tillage management include weed control, the need for combining it with irrigation for optimal management adoption and the difficulties in using it without using glyphosate.

Temperature is important for this SICS. Autumn and early winter should be mild to promote cover crop growth, followed by a cold January or February to have winter kill the cover.

The approach requires a no-till seed drill. The application of this SICS requires a medium level of expertise and a correct application is critical for its success. Due to the need for equipment the technique might find better uptake at larger farms.

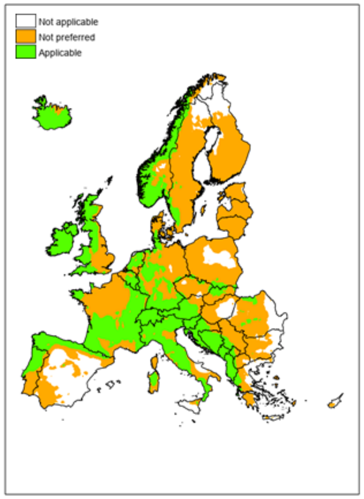
After a conversion time of likely a few years, this SICS could reduce production costs, while maintaining high yields. Financial incentives at the start would therefore increase the uptake. It should be noted that the economic outcomes of this SICS are likely varying depending on weather conditions.

Understanding and proven effectiveness of the technique are critical for its adoption. Furthermore, the willingness of the farmer and the availability of subsidies (together with the financial capability of the farmer) are likely to stimulate its uptake.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Italy: Conservation tillage and deep rooting tillage radish to alleviate compaction, and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for No till and cover crop)
Europe



Slope
(classified for No till and cover crop)
Europe

Soil depth
(classified for No till and cover crop)
Europe

Landscape position
(classified for No till and cover crop)
Europe

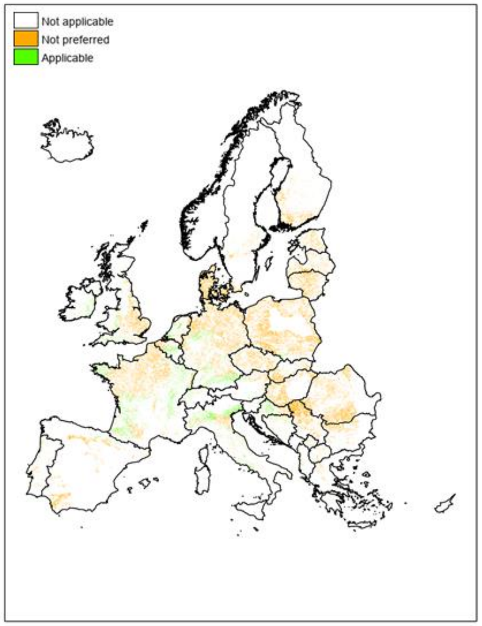
Land use
(classified for No till and cover crop)
Europe

Aridity index
(classified for No till and cover crop)
Europe

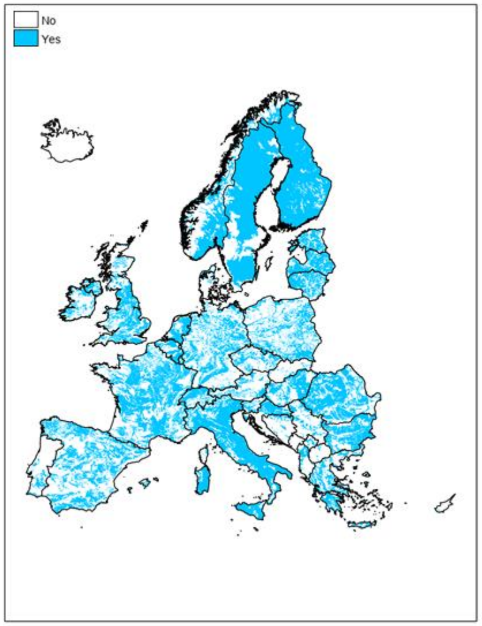
Soil texture
(classified for No till and cover crop)
Europe

Soil fertility
(classified for No till and cover crop)
Europe

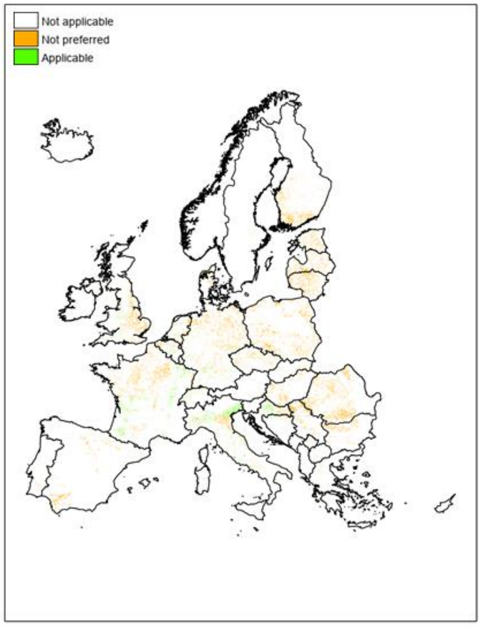
Overall applicability
No till and cover crop
Europe



Relevance
No till and cover crop
Europe



Combined
No till and cover crop
Europe



3.1.6. Crop rotation

Crop rotations in combination with reduced tillage, and potentially together with N fertilisation, aim to increase the overall sustainability and quality of the soil and thus mitigate compaction, organic carbon loss and erosion that occur in conventional tillage practices. In the study site in Hungary a maize wheat bi-culture was tested: maize-maize-wheat-wheat, with different levels of mineral N fertilisation.

Additional application and adoption factors:

The combination of crop rotation, minimum tillage and N fertiliser is likely to result in similar, and potentially higher, yields than achieved with conventional tillage, while reducing labour costs. The availability of organic manure through livestock in the farming system facilitates the adoption as there is no need to purchase (farm yard or green) manure and hence the cost-benefit ratio of the SICS improves.

The application of this SICS is less favourble in sandy soils as the effect of the rotation will be less. The SICS is also more prone to drought when applied under rainfed conditions.

A medium level of expertise would be required for this SICS. It can be applied at any farm type and to farms of any size.

It is expected to take 5-10 years before it is possible to see soil quality improvements after application of the SICS and positive effects are likely noticeable for 3-5 years after quitting the practice.

A barrier for this SICS is the increased probability of weed infestation, which was found problematic especially in a socio-cultural context.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Hungary: Monitoring and analysis of soil cultivation and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Crop rotation)
Europe

Slope
(classified for Crop rotation)
Europe

Soil depth
(classified for Crop rotation)
Europe

Landscape position
(classified for Crop rotation)
Europe

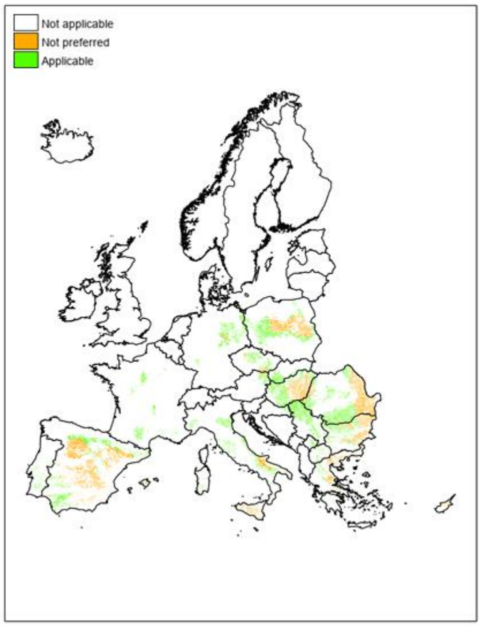
Land use
(classified for Crop rotation)
Europe

Aridity index
(classified for Crop rotation)
Europe

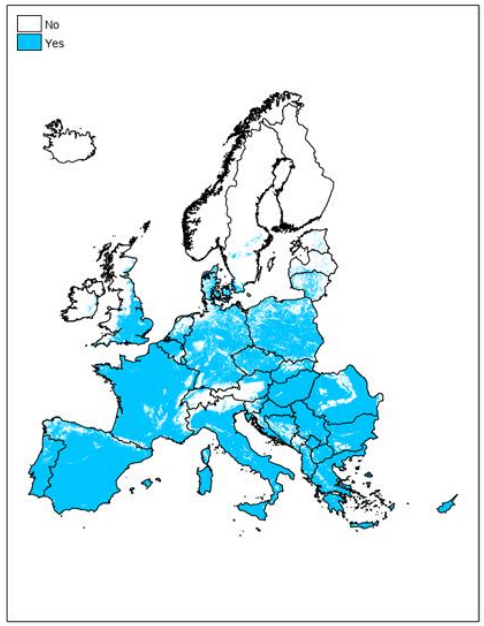
Soil texture
(classified for Crop rotation)
Europe

Soil fertility
(classified for Crop rotation)
Europe

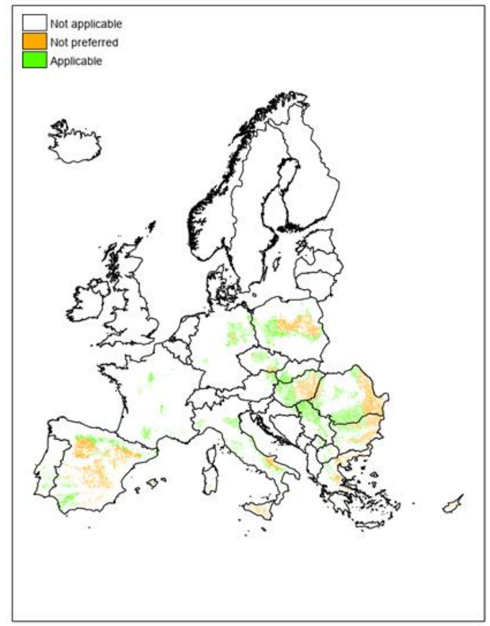
Overall applicability
Crop rotation
Europe



Relevance
Crop rotation
Europe



Combined
Crop rotation
Europe



3.1.7. Minimum tillage and plant nutrition

Minimum or reduced tillage can, especially in combination with plant residues on the soil surface, reduce water and wind erosion, evaporation, and warming of the soil in summer. The latter two result in higher humidity of the soil which can lead to better conditions for winter crops. In addition, minimum tillage can mitigate the decline in soil organic carbon compared to conventional ploughing. In the Czech study site different tillage practices were explored and these were combined with different fertilization treatments.

Additional application and adoption factors:

Minimum tillage is most suited to drier areas where cereals, oilseeds, legumes or corn are cultivated. The SICS doesn’t require any investment costs and shallower soil tillage results in lower fuel consumption, less wear and tear of work tools and labour savings. However, localised heavy rains during the vegetation season cause problems to the soil and crops.

The higher yields and improved cost-benefit ratio that can be obtained with this SICS over time facilitate its uptake, as does the greater year-to-year stability of crop yields. Because it will take a few years before benefits are likely to outweigh the costs, financial incentives in the introduction period would facilitate the uptake of this SICS. Expected future legislative requirements and/or subsidies depending on carbon storage in the soil will also facilitate adoption of this SICS.

Disadvantages of this SICS are the higher content of nutrients with low mobility in the soil in the tilled (10 cm in this experiment) surface layer. This requires the application of calcium (or magnesium) to maintain a good soil structure and related water infiltration into the soil. Growing catch crops and liming can help to ameliorate this issue.

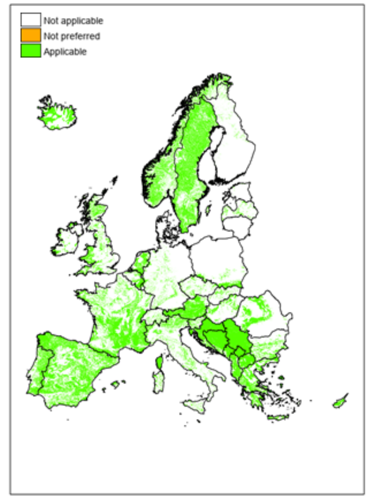
Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Czech Republic: Effect of tillage and fertilisation on crops and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Min tillage and plant nutrition)
Europe

Slope
(classified for Min tillage and plant nutrition)
Europe

Soil depth
(classified for Min tillage and plant nutrition)
Europe



Landscape position
(classified for Min tillage and plant nutrition)
Europe

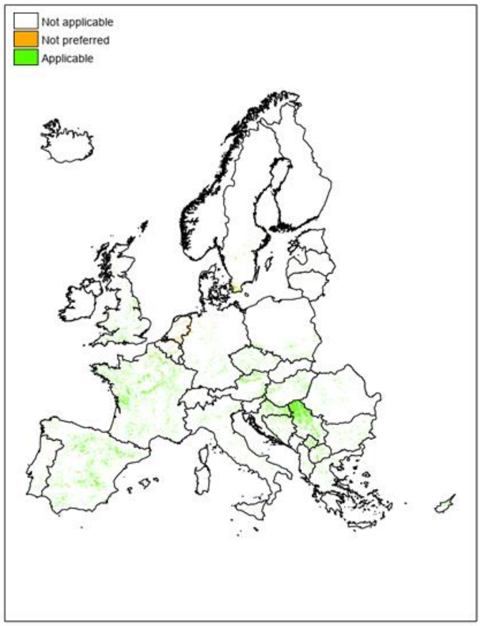
Land use
(classified for Min tillage and plant nutrition)
Europe

Aridity index
(classified for Min tillage and plant nutrition)
Europe

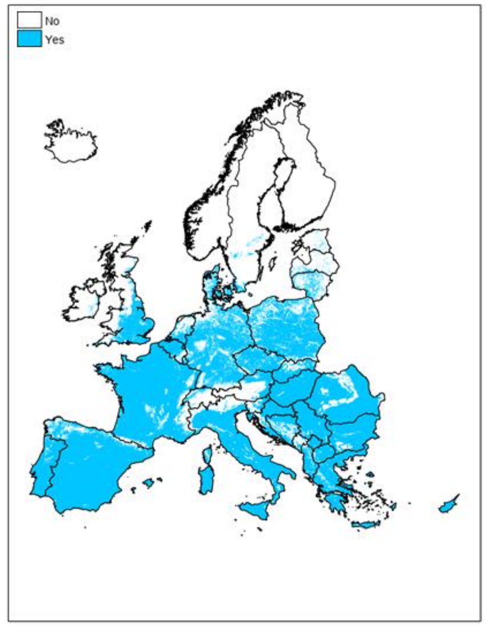
Soil texture
(classified for Min tillage and plant nutrition)
Europe

Soil fertility
(classified for Min tillage and plant nutrition)
Europe

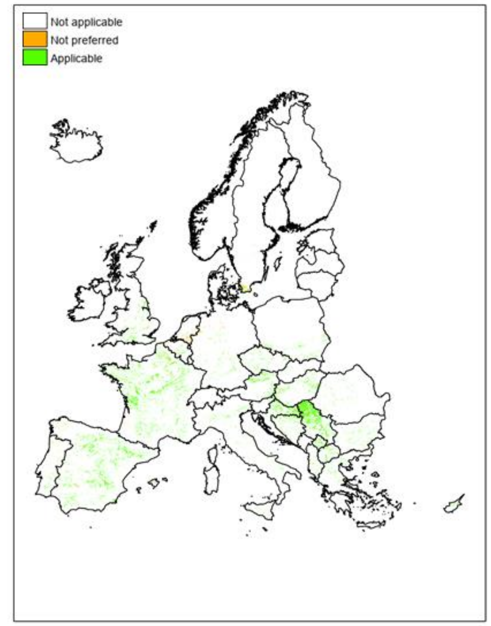
Overall applicability
Min tillage and plant nutrition
Europe



Relevance
Min tillage and plant nutrition
Europe



Combined
Min tillage and plant nutrition
Europe



3.1.8. Cover crop, liming, manure

A combination of cover crops / intercropping, liming and manure can be used to increase soil organic matter and water holding capacity, decrease soil acidity, and improve soil structure and N fixation. In the Polish study site, the effects of these soil management practices on crop yields were explored individually and in combination.

Additional application and adoption factors:

Climate conditions impact on yield: moist years have a significant positive impact on yield compared to dry years. Too little rainfall can cause issues for this practice, together with a low temperature at the beginning of the growing season and a short length of the growing season.

The combination of practices leads to higher increases in crop yield and dry gluten content compared to a single practice. However, yield increases do not seem to compensate for additional production costs and consequently financial support would be recommended to increase the adoption of this SICS. In addition, direct discussions and demonstration days would be important for the uptake of this SICS.

This SICS is a socially accepted practice, its uptake strongly depends on the willingness of the farmer, and can be facilitated by the availability of subsidies. Proven effectiveness also helps in the uptake of this SICS.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Poland: Effects of liming, manure and cover crops on crop yields and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

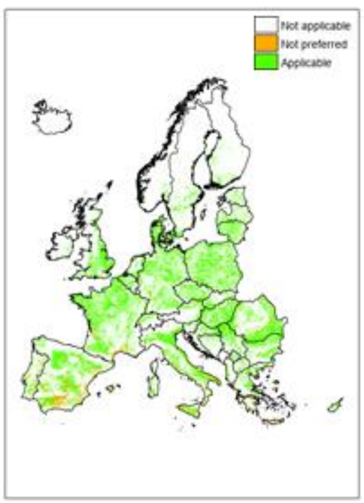
Precipitation
(classified for Cover crop, liming, manure)
Europe

Slope
(classified for Cover crop, liming, manure)
Europe

Soil depth
(classified for Cover crop, liming, manure)
Europe

Landscape position
(classified for Cover crop, liming, manure)
Europe

Land use
(classified for Cover crop, liming, manure)
Europe

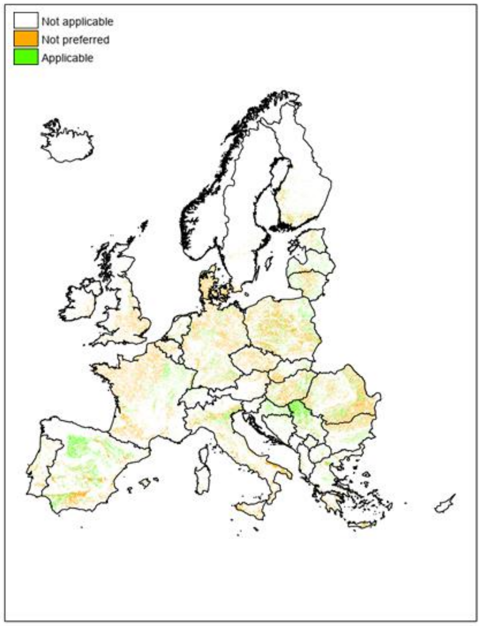


Aridity index
(classified for Cover crop, liming, manure)
Europe

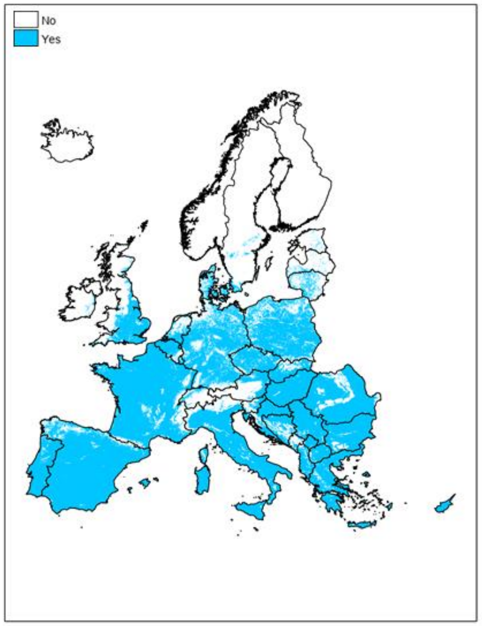
Soil texture
(classified for Cover crop, liming, manure)
Europe

Soil fertility
(classified for Cover crop, liming, manure)
Europe

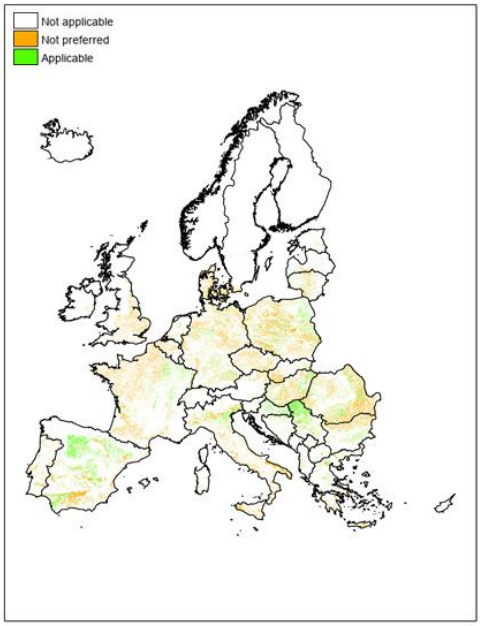
Overall applicability
Cover crop, liming, manure
Europe



Relevance
Cover crop, liming, manure
Europe



Combined
Cover crop, liming, manure
Europe



3.1.9. Cover crops in orchards

Cover crops and pruning residues were applied in the Spanish study site with the aim to increase soil organic matter and reduce water and wind erosion. This was combined with standard and regulated deficit irrigation to assess impact on yield.

Additional application and adoption factors:

Results suggest that weather conditions impact on the effectiveness of cover crops to improve SOC. Benefits of increasing nutrient availability are recognised by farmers and facilitate the uptake of the SICS. Furthermore, results show that the SICS can result in higher yield. There seems to be a trade-off between increase and decrease of some costs with no significant differences on the total costs observed.

Due to the local conditions of the Spanish study site, the aridity index (P/PET) is too low in summer to continue with the cover crop after March.

Farmers are concerned about the scarce water supply and low rainfall as well as the operational costs and the size of exploitation. Additional barriers include their resistance to new practices, the lack of awareness and information, the lack of access to technology and machinery and a maladapted policy setup with a lack of enforcement and monitoring. In addition, there is a risk of lower yields, if weeds and cover crops are not eliminated on time.

Some of the barriers of using cover crops or pruning residues in combination with regulated deficit irrigation could be removed by providing training and disseminating the efficiency potential of the SICS as wind erosion control, together with access to technology and machinery, potentially through management agreements.

In addition to potential soil quality and yield benefits, the reputation of the farmers for applying improved sustainability practices is seen as an enabler for this SICS, together with the willingness and age of the farmer, with younger farmers being more likely to adopt. An improved understanding and application of the technique by peers also contributes to its uptake as do subsidies.

The combined applicability map on the next page only delineates a small area of Europe to be applicable and relevant for this practice. This is however due to the narrow choice of land use (orchards) and aridity index as this was what the SICS was investigated for. Cover crops in general can be more widely applied, as is demonstrated by the various study sites in which this SICS is investigated.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Spain: SICS, including minimum tillage, for improving soil health and Spain: Irrigation, no-till, and cover crops for improving soil health and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Cover crops in orchards)
Europe

Slope
(classified for Cover crops in orchards)
Europe

Soil depth
(classified for Cover crops in orchards)
Europe

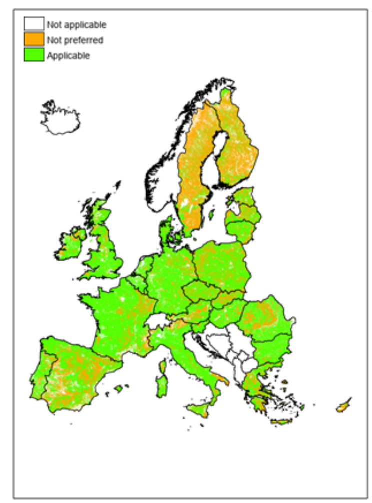
Landscape position
(classified for Cover crops in orchards)
Europe

Land use
(classified for Cover crops in orchards)
Europe

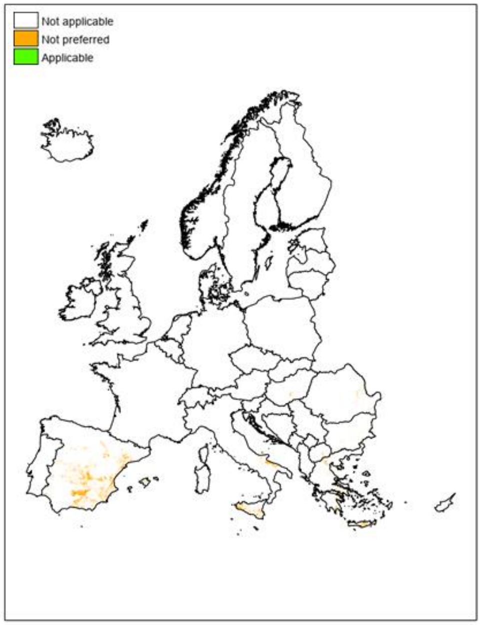
Aridity index
(classified for Cover crops in orchards)
Europe

Soil texture
(classified for Cover crops in orchards)
Europe

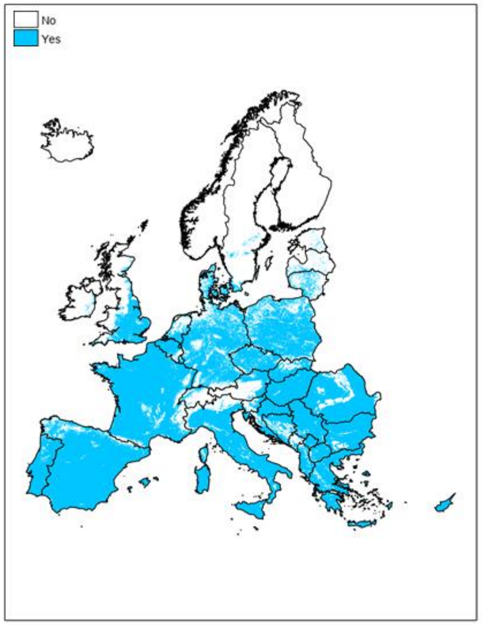
Soil fertility
(classified for Cover crops in orchards)
Europe



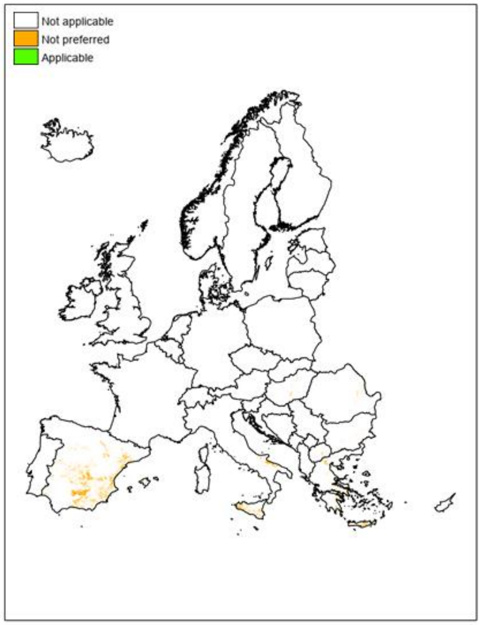
Overall applicability
Cover crops in orchards
Europe



Relevance
Cover crops in orchards
Europe



Combined
Cover crops in orchards
Europe



3.1.10. Early sowing of wheat

In the French study site early sowing of wheat was applied, based on the Bonfils method whereby the sowing rate is divided by two per month in advance, with wheat sown with companion plants. This approach replaces conventional sowing methods which contribute to soil erosion, where wheat is sown in mid-November with autumnal tillage.

Additional application and adoption factors:

The success of this SICS is highly linked to the weather conditions (i.e. good sowing conditions in August or September and good mechanical weeding conditions in Autumn). Heavy rainfall over the winter period might cause problems as well. Longer-term experiments would be needed to assess the impact of the climate variability as well as the effectiveness of the SICS to mitigate erosion and increase soil organic carbon.

This practice requires a medium level of expertise, while its success is highly critical upon correct application.

In the current setup the SICS was not economically viable and would need further development with companion cropping and altering the sowing rates. Not having an economically viable practice would limit its uptake.

Additional socio-economic factors listed to enhance the adoption include the awareness and understanding of the technique, the application of the technique by peers, the proven effectiveness, and the willingness and education level of the farmer (or other person implementing the technique). In addition, a larger farm size might facilitate its uptake.

Because the technique is very new, innovative farmers that can act as early adopters or champions would stimulate the further testing, development and adoption of the SICS.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet France: Early sown wheat for reducing soil erosion and nutrient loss and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Early sowing of wheat)
Europe

Slope
(classified for Early sowing of wheat)
Europe

Soil depth
(classified for Early sowing of wheat)
Europe

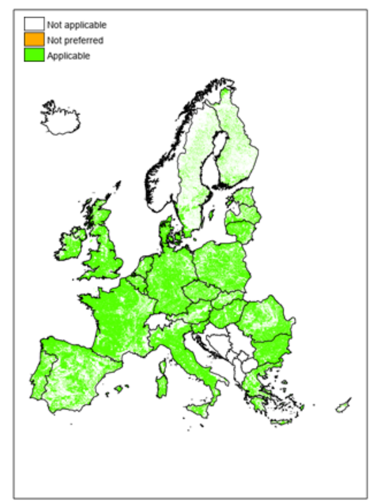
Landscape position
(classified for Early sowing of wheat)
Europe

Land use
(classified for Early sowing of wheat)
Europe

Aridity index
(classified for Early sowing of wheat)
Europe

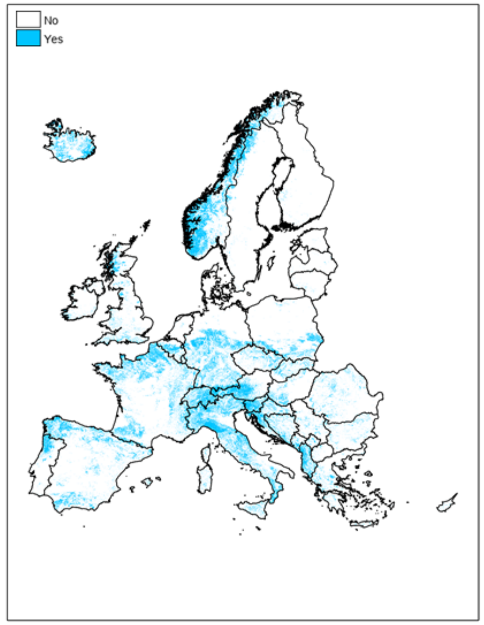
Soil texture
(classified for Early sowing of wheat)
Europe

Soil fertility
(classified for Early sowing of wheat)
Europe

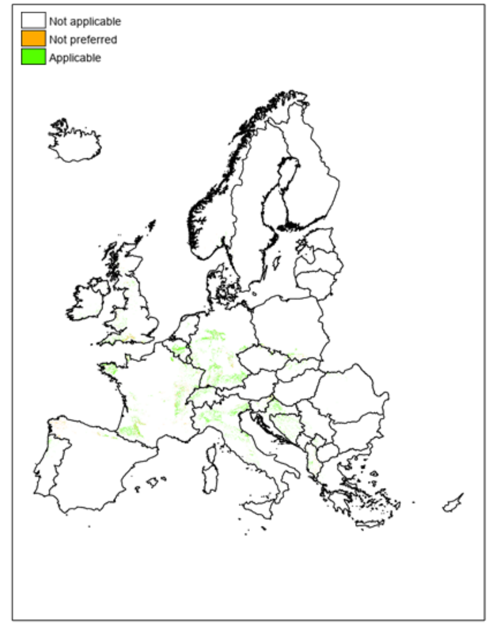


Overall applicability
Early sowing of wheat
Europe

Relevance
Early sowing of wheat
Europe



Combined
Early sowing of wheat
Europe



3.1.11. No tillage

No tillage can improve soil health by limiting erosion, reducing organic matter decline, keeping soil microbiology intact, limiting compaction through less machine passes across fields as well as by reducing fuel use and related emissions. In the Greek study site in Crete different tillage practices were tested in olive orchards aiming to improve above-mentioned soil health benefits.

Additional application and adoption factors:

Enablers for adoption of the SICS are the effectiveness of the approach to limit erosion, improve soil health and maintain a good soil structure.

The cost-benefit ratio is expected to be positive as there are cost savings because there is no tillage effort and machinery required while yields are expected to be the same compared to a practice that includes tillage.

Sources and more information:

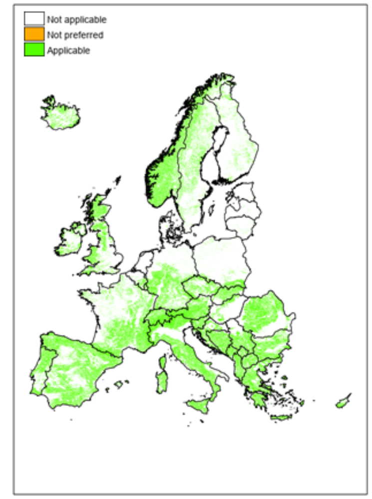
The WP4 & WP6 questionnaires, the fact sheet Greece: Effects of tillage practices on soil erosion in olive groves and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for No tillage)
Europe

Slope
(classified for No tillage)
Europe

Soil depth
(classified for No tillage)
Europe

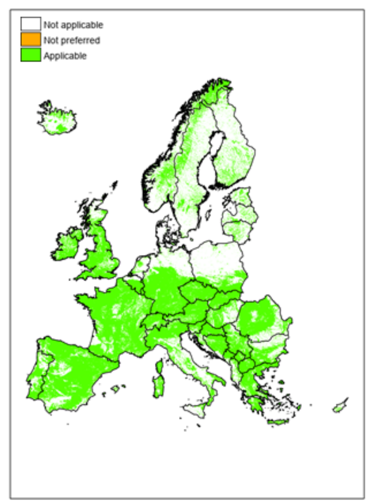
Landscape position
(classified for No tillage)
Europe



Land use
(classified for No tillage)
Europe

Aridity index
(classified for No tillage)
Europe

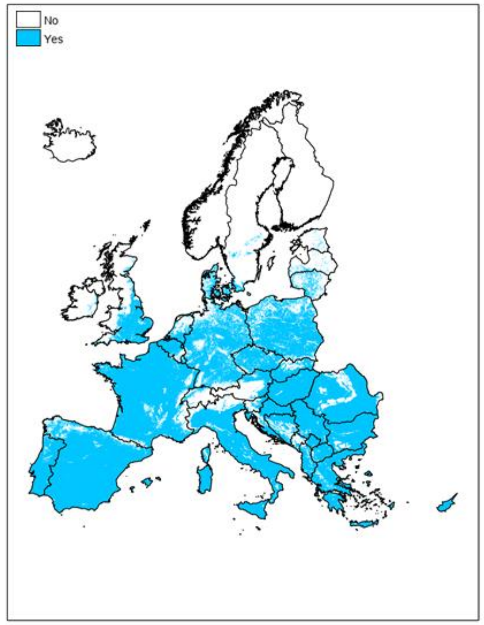
Soil texture
(classified for No tillage)
Europe



Soil fertility
(classified for No tillage)
Europe

Overall applicability
No tillage
Europe

Relevance
No tillage
Europe



Combined
No tillage
Europe

3.1.12. Subsoil loosening

Mechanical loosening with or without the addition of fresh organic material was applied to achieve improvement in the subsoil. This SICS, which was investigated in the Swedish study site, aims to stimulate biological activity and stabilization of the soil structure at a lower density, enabling roots to grow deeper. A less compacted soil structure will enable roots to take up more water and nutrients by exploring a greater volume of soil, resulting in higher yields.

Additional application and adoption factors:

In the option with the addition of fresh organic material a subtiller is used to blow in straw pallets at 40 cm depth to increase the porosity of the soil. In addition, a tank for transporting organic material is required. Currently the technique is still in an experimental stage. However, the expectation is that it will be applied only once every 5-10 years or so, which makes it likely that the work is done by contractors who bring their own machinery.

The timing of the implementation is critical as it should not be too wet. Under wet conditions it isn’t possible to drive with the machine and apply deep tillage. Due to the tractor operation required, the technique isn’t suited for steeper slopes and a subsoil needs to be present. Although the level of expertise required to apply the technique is low, correct application is critical for its success.

As this technique is intended to alleviate compaction, its application is most relevant to soils with a high level of compaction in which there is a limitation of root growth in the subsoil.

Injecting large amounts of organic material may be economically unviable due to technical difficulties and machinery costs. Uptake is furthermore hampered by the limited capacity of farm advisors to provide information about these practices. In addition, the inflexible (Swedish) subsidy system makes it difficult for farmers to experiment or change practices.

Although the short-term pilot in the study site showed that subsoiling had a positive impact on root growth and rooting depths, it did not significantly affect yields. Longer-time studies could provide more insight in the repeated subsoil loosening treatments and effects over longer time periods.

Additionally, a main factor for encouraging the adoption of straw incorporation would be a well-functioning advisory system, allowing farmers to make informed decisions.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Sweden: Incorporating straw into the upper subsoil to improve soil quality and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Subsoil loosening)
Europe

Slope
(classified for Subsoil loosening)
Europe

Soil depth
(classified for Subsoil loosening)
Europe

Landscape position
(classified for Subsoil loosening)
Europe

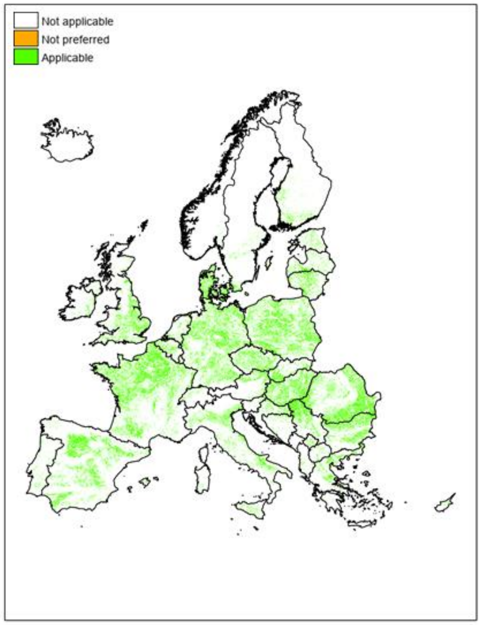
Land use
(classified for Subsoil loosening)
Europe

Aridity index
(classified for Subsoil loosening)
Europe

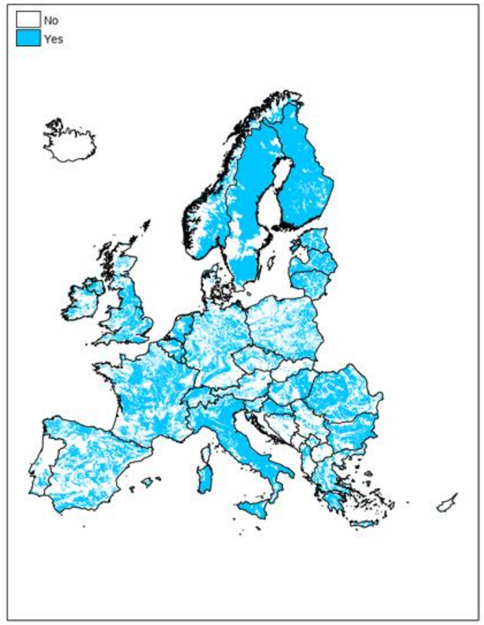
Soil texture
(classified for Subsoil loosening)
Europe

Soil fertility
(classified for Subsoil loosening)
Europe

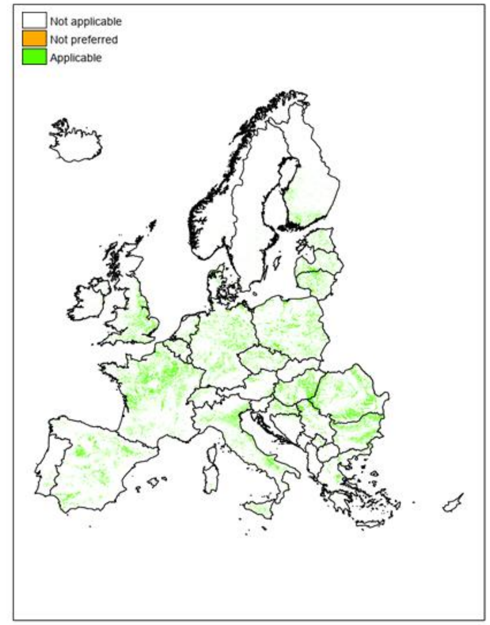
Overall applicability
Subsoil loosening
Europe



Relevance
Subsoil loosening
Europe



Combined
Subsoil loosening
Europe



3.1.13. Subsoiling

Subsoiling was applied in the Romanian study site to improve the soil structure, reduce compaction, and increase fertility. Periodic subsoiling can prevent the formation of a hardpan layer at the base of tillage depth.

Additional application and adoption factors:

On clayey soil, subsoiling can be used in crop rotations with deep rooting system crops / legumes to further enhance soil quality.

It is important that subsoiling is carried out at the right time (it cannot be too dry) and only on soil types suited to this practice. Furthermore, variation in weather between the years likely results in different yield impacts.

As this technique requires a subsoiler, it can only be applied to flat and gentle slopes. Farmers can own the equipment themselves, but often rent it from other farmers. The level of expertise required to apply the technique is low. Pest and weed control are commonly applied together with this technique.

The SICS is expected to have higher costs (application of the subsoiler) but also higher benefits (improved yield) compared to doing nothing. The effects of the technique are immediate. Positive impacts become less noticeable over time and over a period of 2-3 years the compaction is likely to return.

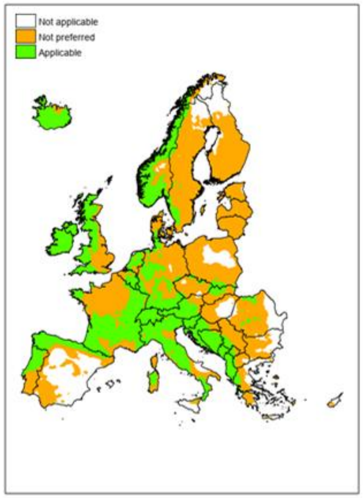
This SICS is most likely to be used by commercial farmers with a market orientation that aim to maximize production.

Socio-economic aspects relevant for the adoption of this SICS include the willingness and education level of the farmer (or other person implementing the technique), the awareness and understanding of the technique, its application by peers and the proven effectiveness of the technique.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Romania: Tillage for improving soil health and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Subsoiling)
Europe



Slope
(classified for Subsoiling)
Europe

Soil depth
(classified for Subsoiling)
Europe

Landscape position
(classified for Subsoiling)
Europe

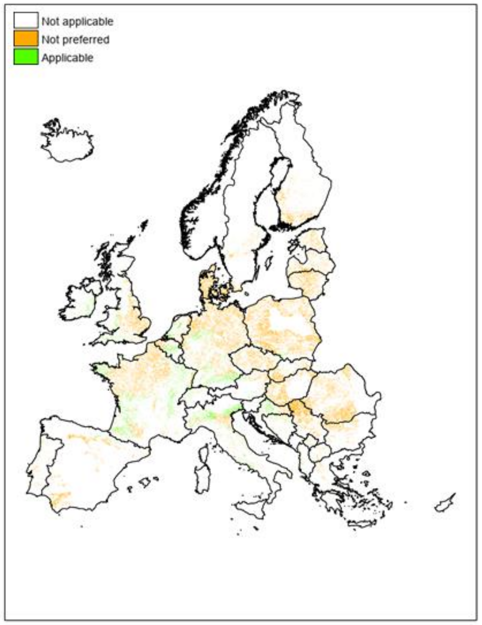
Land use
(classified for Subsoiling)
Europe

Aridity index
(classified for Subsoiling)
Europe

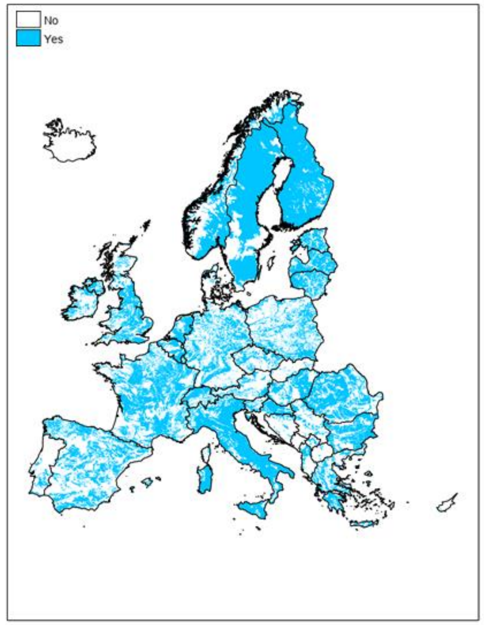
Soil texture
(classified for Subsoiling)
Europe

Soil fertility
(classified for Subsoiling)
Europe

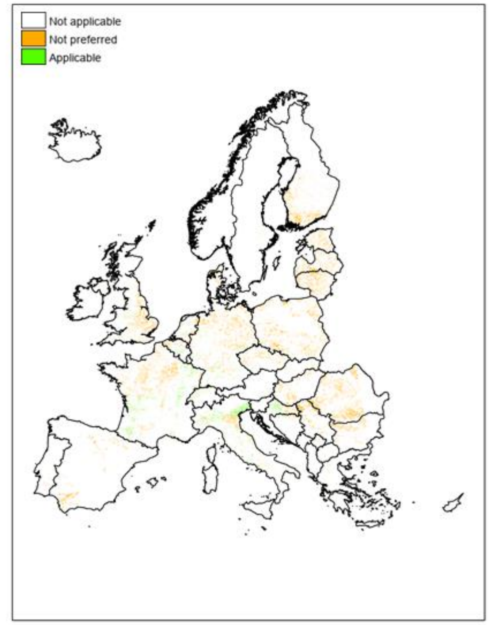
Overall applicability
Subsoiling
Europe



Relevance
Subsoiling
Europe



Combined
Subsoiling
Europe



3.1.14. Green manure

In the Danish study site, a cover crop was under-sown to improve the soil physical, chemical and biological properties, and in addition reduce the yield gap between organic and conventional production.

Additional application and adoption factors:

The costs of the cover crops used in this experiment were low as the ryegrass that was used was under-sown alongside cereal seeds. Extra costs of cover crops, however, were higher than the economic savings of reducing N leaching.

The inclusion of one year of legume-based ley in the rotation in addition to the cover crop seems to have a positive impact on earthworm abundance, which points to a joint effect of good quality litter availability and reduced soil disturbance by cultivation.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet DK: Introducing cover crops into arable rotations and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Green manuring)
Europe

Slope
(classified for Green manuring)
Europe

Soil depth
(classified for Green manuring)
Europe

Landscape position
(classified for Green manuring)
Europe

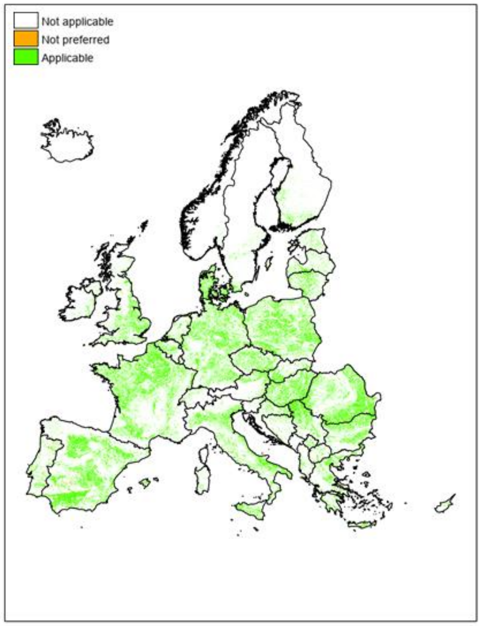
Land use
(classified for Green manuring)
Europe

Aridity index
(classified for Green manuring)
Europe

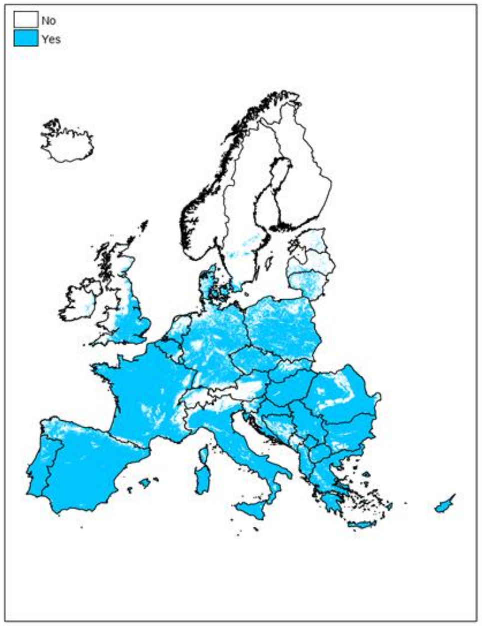
Soil texture
(classified for Green manuring)
Europe

Soil fertility
(classified for Green manuring)
Europe

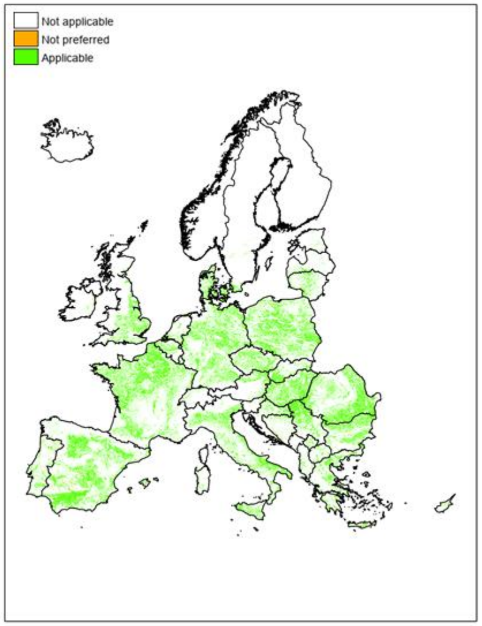
Overall applicability
Green manure
Europe



Relevance
Green manure
Europe



Combined
Green manure
Europe



3.1.15. Deep-rooting grass ley cultivars

In the UK study site the potential of deep-rooting grass leys for reducing flood risk and increasing soil organic carbon, whilst maintaining food production was explored.

Festulolium, ryegrass (Lolium sp.) hybrids with Meadow Fescue (Festuca pratensis) and Tall Fescue (F. arundinacea) have been developed for their deep rooting characteristics, primarily to improve drought resistance. They also have the potential to increase water infiltration rates by around 50%. Cocksfoot (Dactylis glomerata) cultivars have also been developed for their deep-rooting characteristics but have not been tested for their potential to deliver ecosystem services. These alternative grass leys could, therefore, offer a solution for reducing soil compaction and flood risk by improving soil structure and porosity for better water infiltration and holding capacity. They could potentially also help to sequester carbon below the plough layer (approx. 30 cm).

Additional application and adoption factors:

In the application of the SICS, good sowing conditions (moderate rainfall and temperature) in spring or autumn are required depending on the time of sowing. Otherwise, the SICS is tolerant of a wide range of rainfall and temperature conditions.

When the technique is applied in arable rotations it assumes that livestock is available to graze the grass or eat the grass cut for hay/silage.

Factors listed to encourage the adoption of grass leys in the rotation are that deep-rooting grass leys are simple to implement with existing practices and that they may help with blackgrass control. Additional socio-economic factors listed as relevant for its adoption were the awareness and understanding of the technique and the willingness of the farmer to apply it. In addition, proven effectiveness of the technique would facilitate its uptake.

Drawbacks mentioned by stakeholders include the limited knowledge amongst farmers about the costs/benefits of the SICS, the lack of awareness about any financial support for farmers, the

5-year rule for permanent pastures preventing ploughing of grass leys after 5 years and Countryside Stewardship preventing conservation of forage.

Furthermore, it was listed that the SICS may not be attractive to wholly arable farmers and that there might be conflicts with the goal of increasing food supply as cereal yields may decline at catchment scale.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet UK: Deep rooting grass leys for improved water infiltration and soil organic matter and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

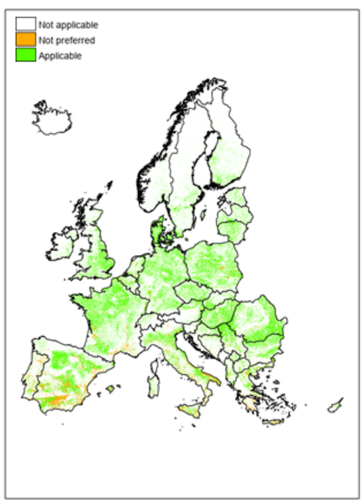
Precipitation
(classified for Deep-rooting grass ley cultivars)
Europe

Slope
(classified for Deep-rooting grass ley cultivars)
Europe

Soil depth
(classified for Deep-rooting grass ley cultivars)
Europe

Landscape position
(classified for Deep-rooting grass ley cultivars)
Europe

Land use
(classified for Deep-rooting grass ley cultivars)
Europe

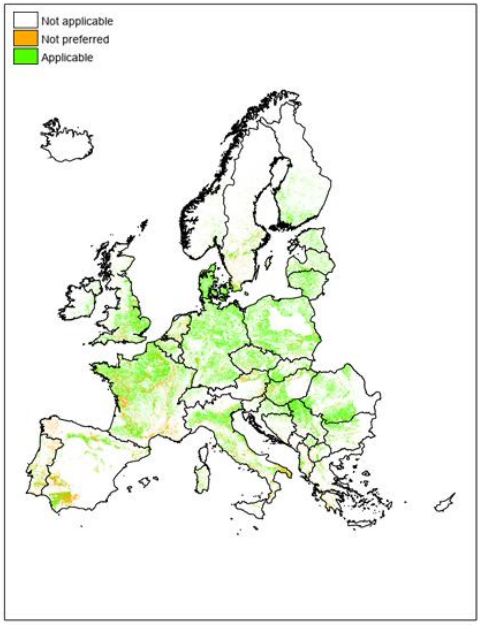


Aridity index
(classified for Deep-rooting grass ley cultivars)
Europe

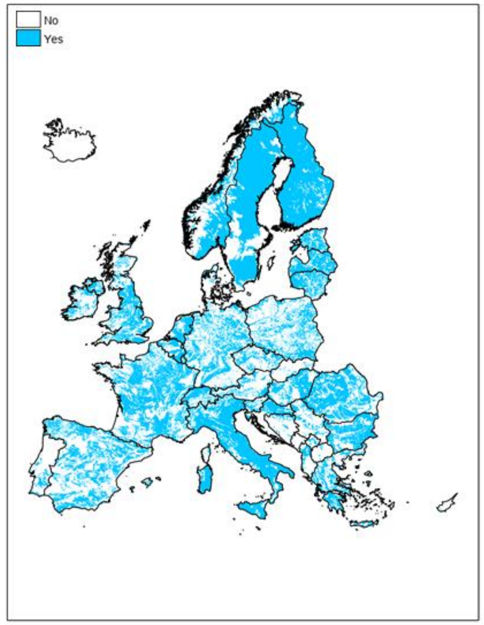
Soil texture
(classified for Deep-rooting grass ley cultivars)
Europe

Soil fertility
(classified for Deep-rooting grass ley cultivars)
Europe

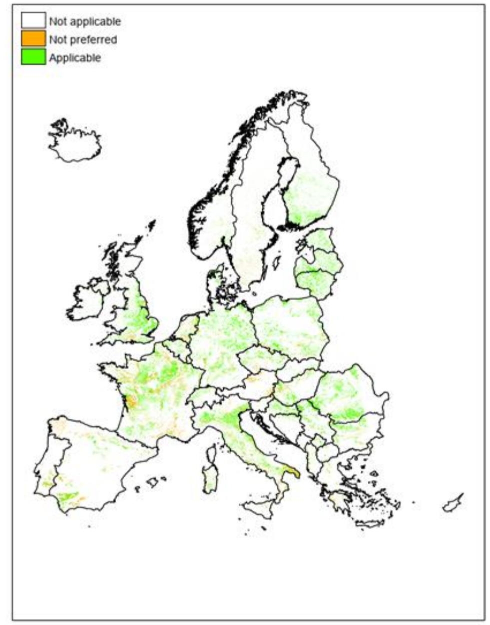
Overall applicability
Deep-rooting grass ley cultivars
Europe



Relevance
Deep-rooting grass ley cultivars
Europe



Combined
Deep-rooting grass ley cultivars
Europe



3.1.16. No till to alleviate compaction

This experiment in the east of England explored the potential of no till in combination with a mycorrhizal inoculant or subsoiling to alleviate or minimise the impacts of compaction compared to a direct drilling system on clay soils. Mycorrhizal inoculants work by boosting root growth which in-turn reduces the effects of compaction, while subsoiling cuts and loosens the soil below the normal tillage depth to break the hardpan and so improving water infiltration and drainage and increasing soil aeration and growth of crop roots.

Additional application and adoption factors:

Subsoiling is not applicable to shallow/stony soils.

Comparing no till plots with cultivation plots, no-till plots were slightly more profitable than the plough plots. Due to the costs of the inoculant and the lower yield, the gross margin was lowest for the plots with mycorrhizal inoculants. Subsoiling seems to result in similar economic benefits as traditional methods such as ploughing, while maintaining soil health advantages.

Climate change objectives likely impact on the adoption of different practices to alleviate compaction, e.g. no till and the use of mycorrhizal inoculants seem to increase the N_20 flux, which might hamper their uptake, although further research regarding all emissions from field operations would be required.

A key factor contributing to the adoption of subsoiling is that it is seen as a well-known and accepted agronomic practice. Nonetheless farmers were not sure how to best time subsoiling and trials are being undertaken to test this. Additional socio-economic factors facilitating its adoption include the awareness and understanding of the technique, the education level and willingness of the farmer and the application of the technique by peers.

Key barriers preventing the adoption of subsoiling and mycorrhizal inoculation include the limited knowledge on costs/benefits and the lack of equipment available for subsoiling.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet UK: No till farming for alleviating soil compaction and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for No till to alleviate compaction)
Europe

Slope
(classified for No till to alleviate compaction)
Europe

Soil depth
(classified for No till to alleviate compaction)
Europe

Landscape position
(classified for No till to alleviate compaction)
Europe

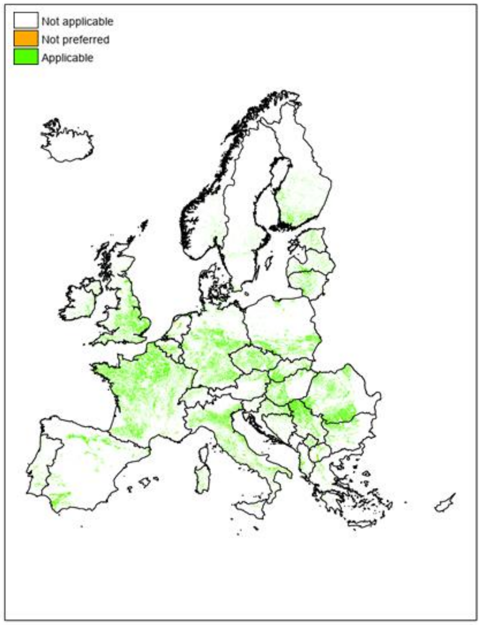
Land use
(classified for No till to alleviate compaction)
Europe

Aridity index
(classified for No till to alleviate compaction)
Europe

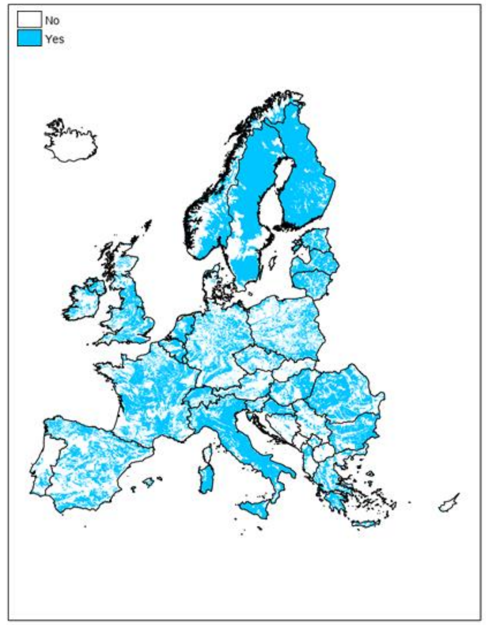
Soil texture
(classified for No till to alleviate compaction)
Europe

Soil fertility
(classified for No till to alleviate compaction)
Europe

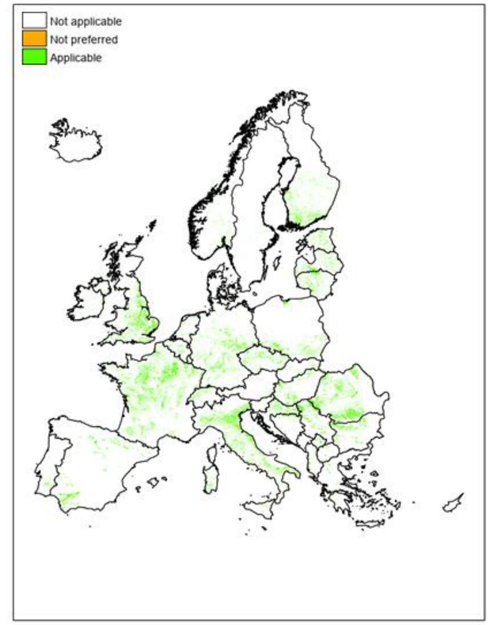
Overall applicability
No till to alleviate compaction
Europe



Relevance
No till to alleviate compaction
Europe



Combined
No till to alleviate compaction
Europe



3.1.17. Organic rice in rotation

Introducing perennial Lucerne in the organic rice cultivation system has the potential to address a set of soil threats in organic production systems as it provides an important organic source of nitrogen due to the biological nitrogen fixation capacity of the legumes, it increases soil organic content due to the introduction of biomass in the soil, and limits weed infestation due to the diversification of the principal crop. In the Portuguese study site this SICS was tested by having a rotation of 2 years of perennial Lucerne followed by 2 years of organic rice.

Additional application and adoption factors:

The tested SICS shows promising results regarding the (slight) increase of the SOM content, the decrease of mineral fertilization use (especially nitrogen, mitigating the risk of nutrient leaching and groundwater pollution), no use of pesticides and an improved income for the farmer.

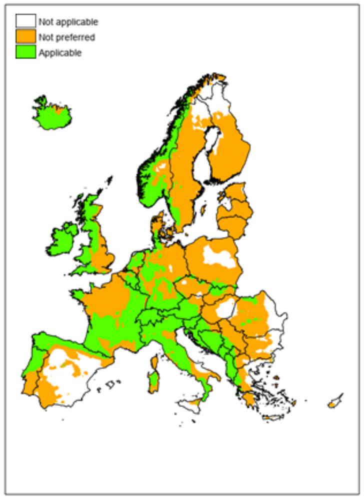
There are however also some barriers listed that can limit the uptake of the SICS, such as increased weed burdens leading to human labour requirements and challenges related to processing and commercializing the rice without having an organic rice sector in the region.

Regarding the latter barrier, there is an emerging niche market for high quality and differentiated products that might overcome existing barriers, especially if this comes with a professionalisation through cooperatives or producer organisations, development of a certification, and good marketing and sales channels that include communicating the value of good quality products and sell them at a fair price.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Portugal: Rotations for improving soil health and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Organic rice in rotation)
Europe



Slope
(classified for Organic rice in rotation)
Europe

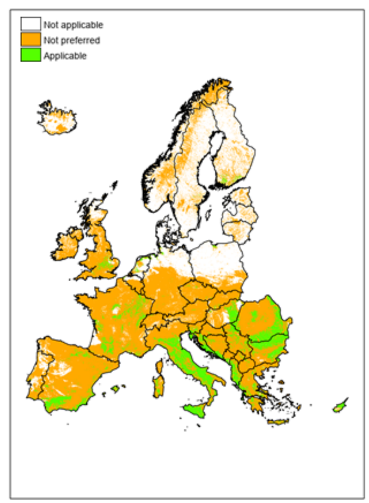
Soil depth
(classified for Organic rice in rotation)
Europe

Landscape position
(classified for Organic rice in rotation)
Europe

Land use
(classified for Organic rice in rotation)
Europe

Aridity index
(classified for Organic rice in rotation)
Europe

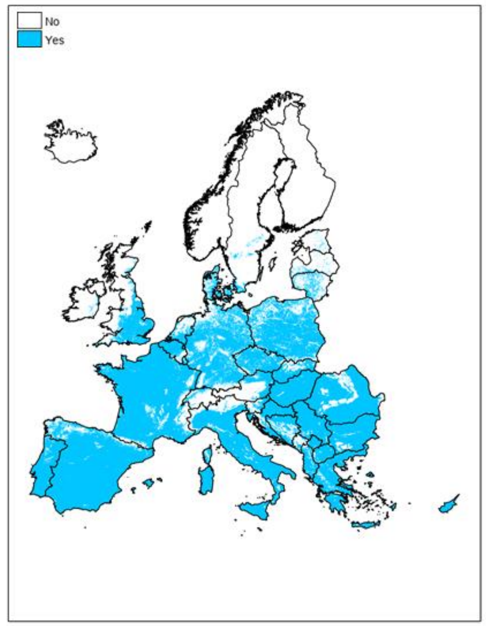
Soil texture
(classified for Organic rice in rotation)
Europe



Soil fertility
(classified for Organic rice in rotation)
Europe

Overall applicability
Organic rice in rotation
Europe

Relevance
Organic rice in rotation
Europe



Combined
Organic rice in rotation
Europe

3.1.18. Succession system

The SICS that was tested in the Portuguese study site is a winter cover crop used as green manure for the principal crop (maize). This is expected to lead to the following benefits: mitigation of nutrient leaching as the biomass produced may result in uptake and immobilization of nutrients during the winter; improved nutrient recycling by providing a source of nutrients to the principal leading to a reduction of the use of mineral fertilizer; and improved weed control as the legumes will compete with weeds, thus resulting in less need for pesticides; and increased soil organic matter content.

Additional application and adoption factors:

The choice of legume cover crops (LCC) plays an important role in the contribution of the SICS to provide the expected benefits. Although all species produced high amounts of biomass, three clover species (crimson, balansa, and arrowleaf clover) performed best in weed control. The weed control capacity of the cover crop is strongly related to legume biomass production. The success in weed control also depends on the early-stage establishment of the cover crops and the soil surface cover. In the study site legumes and weeds allowed an important uptake of nutrients from the soil, contributing to mitigate the leaching of nutrients during spring. This was not, however, the case during winter, the most critical period in terms of nutrient leaching. Further research is needed to explore how sowing dates may affect this.

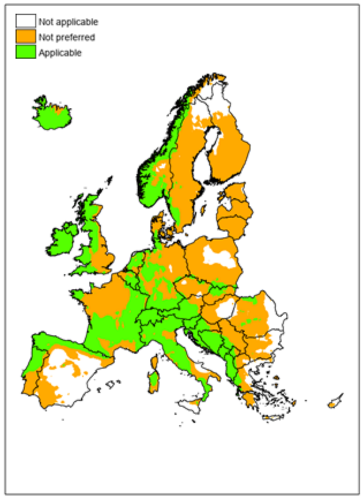
The adoption of the SICS can be facilitated by providing farmers with simple tools, allowing them to estimate accurately the amount of nutrients legumes are able to provide for diverse conditions and the corresponding amount of mineral fertilizer that they could save.

Using the SICS as part of an organic production process makes it more labour intensive than the traditional practice of using pesticides as the remaining weeds would need to be removed manually, which is time consuming and hence expensive. However, crop prices are expected to be higher as well and no pesticides need to be bought.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Portugal: Winter cover crops and succession systems for improving soil health and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Succession system)
Europe

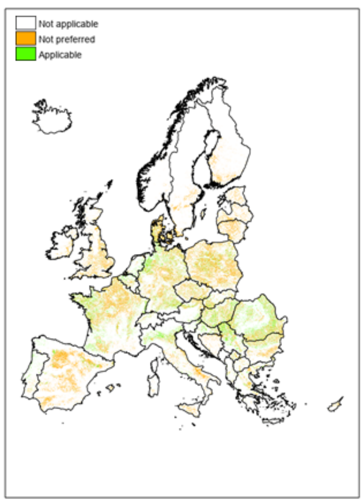


Slope
(classified for Succession system)
Europe

Soil depth
(classified for Succession system)
Europe

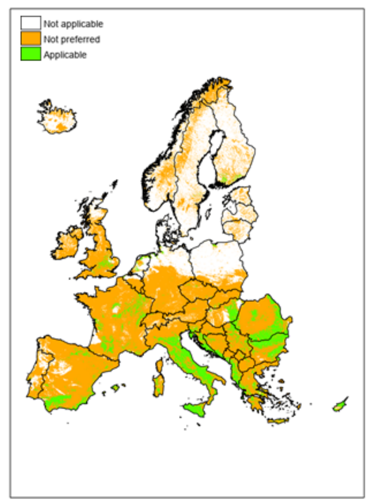
Landscape position
(classified for Succession system)
Europe

Land use
(classified for Succession system)
Europe



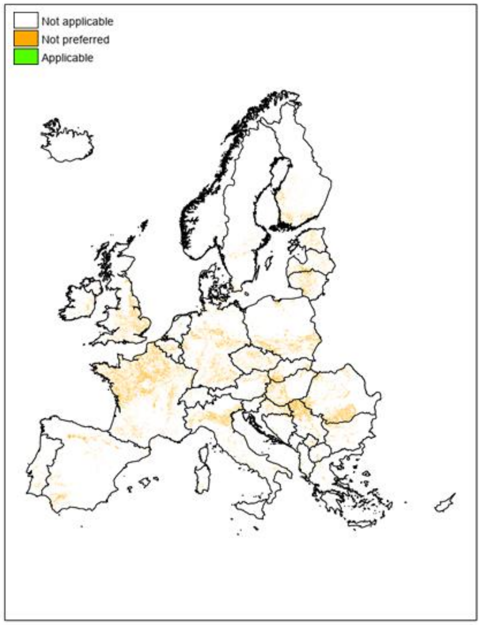
Aridity index
(classified for Succession system)
Europe

Soil texture
(classified for Succession system)
Europe

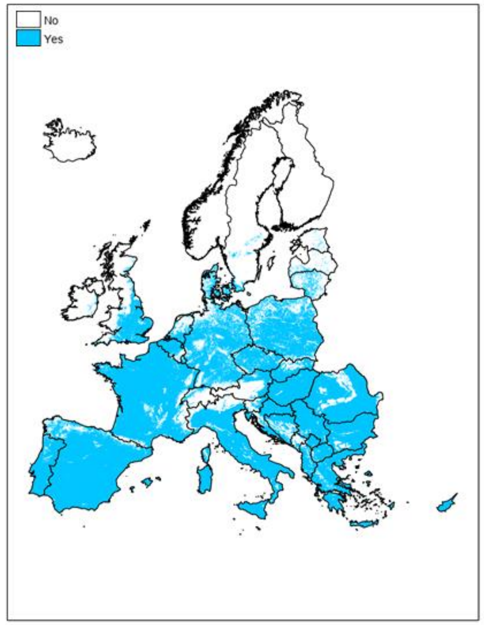


Soil fertility
(classified for Succession system)
Europe

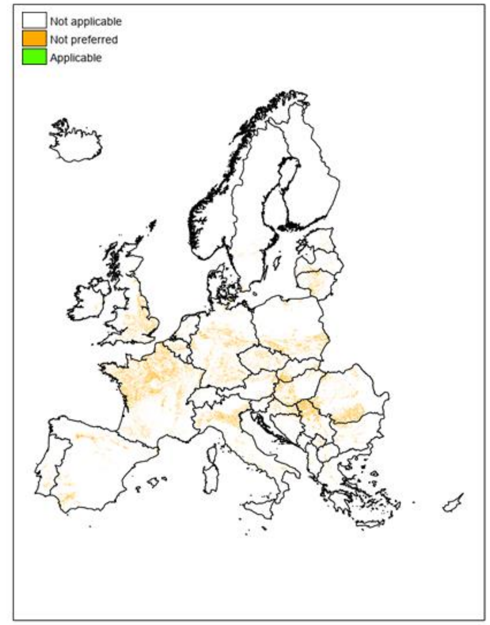
Overall applicability
Succession system
Europe



Relevance
Succession system
Europe



Combined
Succession system
Europe



3.1.19. Organic fertilisation

Urban sewage sludge can be used as an amendment to improve soil quality, as an alternative to using mineral fertilizer and thus contribute to a circular economy. However, it is very controversial amongst others because of the potential heavy metal concentration it brings to the soil. In the Portuguese study site, the impacts of this SICS were tested on soil quality and yield.

Additional application and adoption factors:

Urban sludge application can quickly and significantly improve soil fertility. In the Portuguese study site, it improved pH, SOC content, total nitrogen, available phosphorus and potassium, exchangeable cations ($Ca2+$ and $K+$), and earthworm density.

Special attention however needs to be paid to the adjustment of the mineral fertilization in function of the nutrients contained in the sludge in order to mitigate the risk of nutrient excess leaching to avoid groundwater pollution.

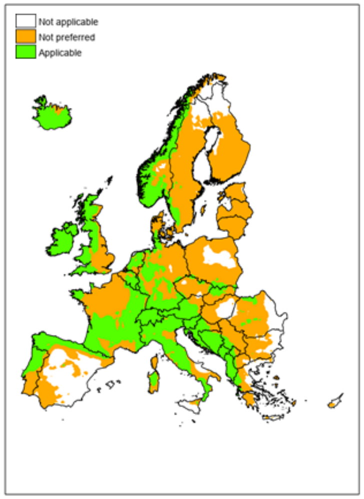
Although the heavy metal concentration progression needs to be monitored carefully, during the short-term study site experiment no alarming increase of soil contamination risk due to heavy metals was observed. Monitoring results showed that concentrations of heavy metals in the soil were slightly higher for copper and chromium, but differences were not significant, and the levels of the heavy metal concentration remained very distant from the limits imposed by law.

Barriers for uptake of this approach are the perceived risks and the farmer’s reputation, as the use of sludge is perceived very negatively by the population in general as well as by the farming community. It is therefore important to disseminate study results on the environmental impact of sludge in seminars as well as to the general public in order to demystify the use of sludge and explain how risks are controlled through sludge management plans.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Portugal: Applying urban sewage sludge to improve soil health and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Organic fertilisation)
Europe

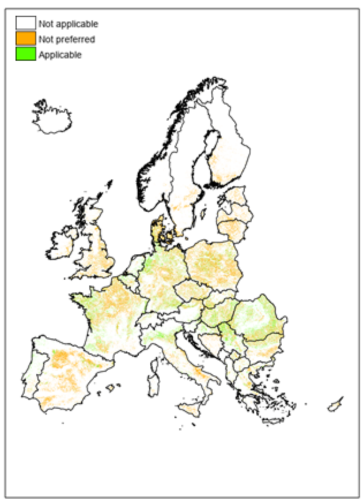


Slope
(classified for Organic fertilisation)
Europe

Soil depth
(classified for Organic fertilisation)
Europe

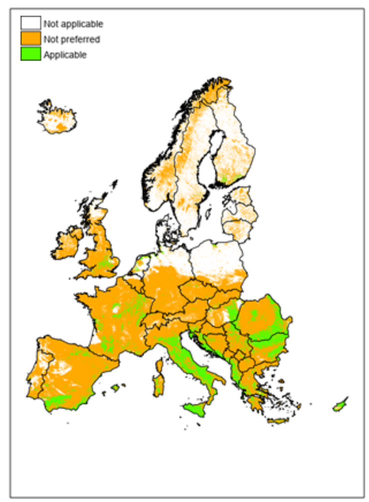
Landscape position
(classified for Organic fertilisation)
Europe

Land use
(classified for Organic fertilisation)
Europe

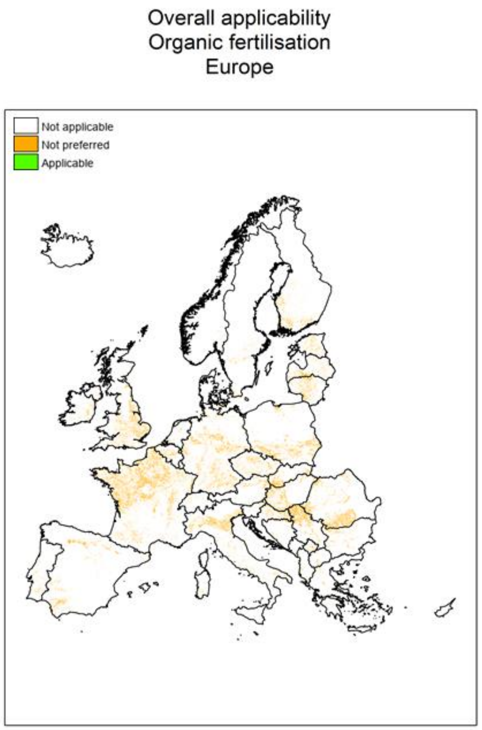


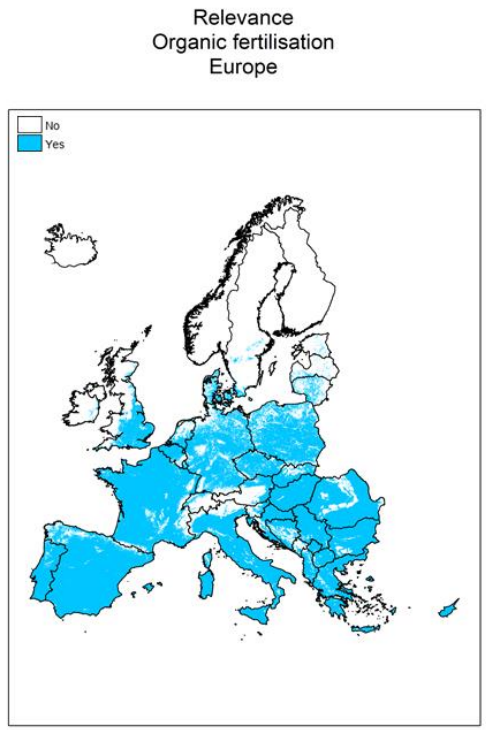
Aridity index
(classified for Organic fertilisation)
Europe

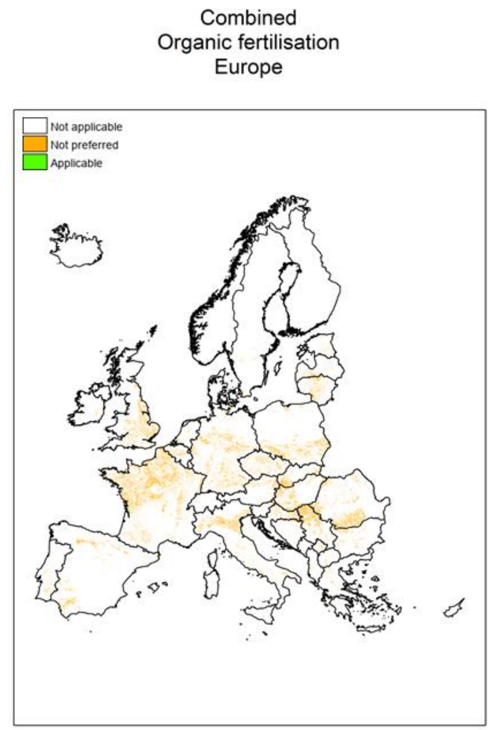
Soil texture
(classified for Organic fertilisation)
Europe



Soil fertility
(classified for Organic fertilisation)
Europe


Overall applicability
Organic fertilisation
Europe
Not applicable
Not preferred
Applicable


Relevance
Organic fertilisation
Europe
No
Yes


Combined
Organic fertilisation
Europe
Not applicable
Not preferred
Applicable

3.1.20. Grass verges

Grass verges or grass strips can be applied (in culture) to reduce the risk of compaction due to heavy machinery. The use of grass verges in-between rows of crops was studied in the Swiss study site.

Additional application and adoption factors:

The green verges are usually kept in the field for 2 years, and afterwards applied on neighbouring fields. For the establishment of the meadow at least 80-90 days are needed.

There is a need for enough rain at the beginning of its establishment. In the Swiss study site where the SICS was applied, this means establishment should be before the end of August. The resistance to drought depends on the rooting and therefore the timing of the sowing.

The best soil for grass is sandy/loam soil (60/40 or 70/30 ratio is optimal). Clay soils require a grass type such as tall fescue and should receive a regular application of organic matter.

The grass verges should increase the natural drainage potential, but if the wrong grass is selected on a clay soil the grass verge can have a negative impact, so the selection of the grass type is important for the effectiveness of the SICS.

Not much expertise is required to apply the SICS. The width of the grass verges can be adapted to meet the specific needs of the farmer, respectively the width of the manuring machines applied. Furthermore, it is important to foster the grass verges so a continuous layer without holes and voids is maintained and the proliferation of weeds avoided.

The conventional practice can use the space taken up by grass verges for cultivating crops and as a result has a bit higher yield. However, this could easily be compensated with the impacts of reduced compaction.

In Switzerland organic farmers receive a financial payback (direct payment) for green areas. A certain amount of green areas are mandatory. The grass verges can be listed as such areas and thus enable the farmer to cultivate all of their field, while also maintaining the required green areas. Such incentives are very beneficial for the adoption of the SICS.

Additional socio-economic factors facilitating the adoption of grass verges include the awareness and understanding of the technique, the interest of the farmer to maintain healthy soils, proven effectiveness of the technique and the application of the technique by peers.

Sources and more information:

The WP4 & WP6 questionnaires and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

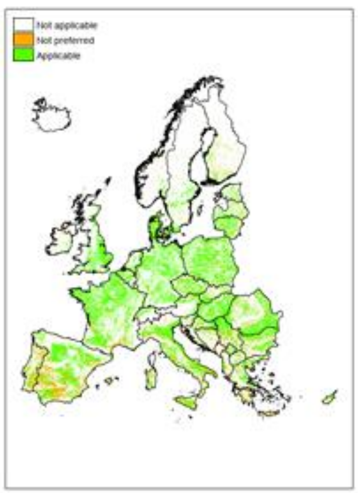
Precipitation
(classified for Grass Verges)
Europe

Slope
(classified for Grass Verges)
Europe

Soil depth
(classified for Grass Verges)
Europe

Landscape position
(classified for Grass Verges)
Europe

Land use
(classified for Grass Verges)
Europe

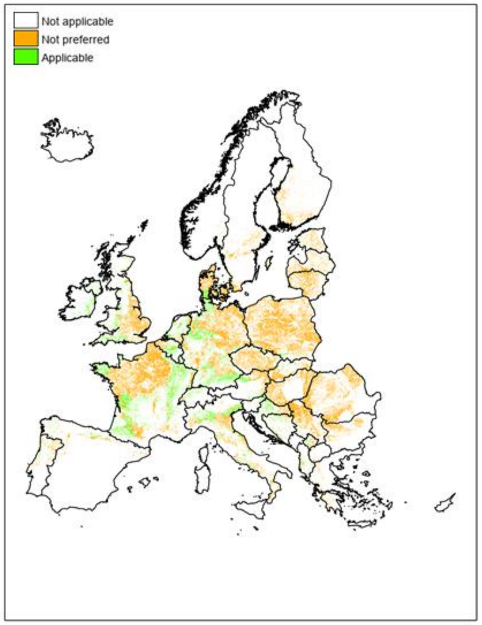


Aridity index
(classified for Grass Verges)
Europe

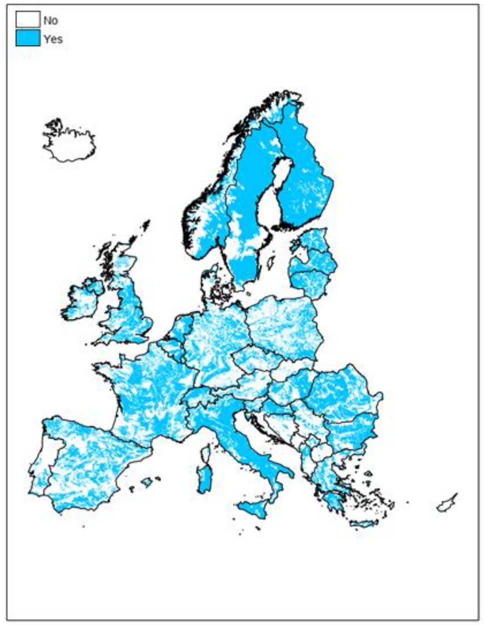
Soil texture
(classified for Grass Verges)
Europe

Soil fertility
(classified for Grass Verges)
Europe

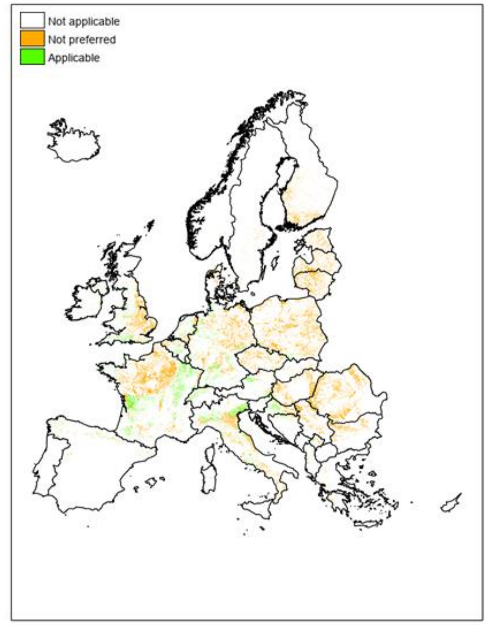
Overall applicability
Grass verges
Europe



Relevance
Grass verges
Europe



Combined
Grass verges
Europe



3.1.21. Underfoot fertilisation after CULTAN

Underfoot fertilisation after Controlled Uptake Long-Term Ammonium Nutrition (CULTAN) aims to improve the nitrogen supply to the plants. It entails specific machinery for application of fertilization directly to the roots. It is used to limit nutrient leaching and increase soil organic carbon and yield. Its use was investigated in the Swiss study site.

Additional application and adoption factors:

As the ammonium transformation in nitrate or in atmospheric nitrogen (nitrification resp. volatilisation) accelerates by increasing temperature, the recommended soil temperature for CULTAN application is 10-15 °C.

The application has to be done with a specific injection machine; therefore the slope is particularly relevant with regard to the navigability with the machine. The N-injection usually happens at a depth of 5-7 cm; hence a minimal soil depth of 10 cm is required. The soil texture itself doesn't play a major role for CULTAN application, but the soil hardness (soft soil (0-1.0 MPa) to semi firm soil (1.0 – 1.6 MPa)) and the water content in the soil (recommended is field capacity or dryer soil condition to prevent any severe soil compaction damage) are relevant. Furthermore, the content of plant assimilable nitrogen in the root depth of the soil is important for successful application. The level of expertise required for application is medium, however for the application to be effective, correct application is critical.

The need for special machinery makes this technique more expensive than a conventional practice. The application through a contractor or the option to invest in an own machine in collaboration with other farmers can limit the investment needed. The expected benefit of a more efficient nitrogen assimilation by plants resulting in higher yields in the Swiss study site was demonstrated during some but not all periods.

This kind of fertilisation could significantly reduce the negative impact on the water bodies compared to conventional practices. This, however, would require a further solution for a proper and financially feasible recycling option of organic manure. Nowadays the costs are higher than those of the conventional practice, as the conventional practice uses the (free) manure.

Further investigations are needed to shed light on the benefits and limitations of CULTAN for a long-term perspective as well as on the barriers and enablers for its uptake. At present key enablers that have been identified are the awareness and understanding of the technique, the willingness of the farmer, application by peers, proven effectiveness and financial capability of the farmer combined with subsidies. Furthermore, uptake is likely to increase if applying the SICS (or similar practices) or its intended environmental impacts become part of legislative requirements.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet and deliverables Switzerland: Fertilisation and amendments for improving soil health. D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

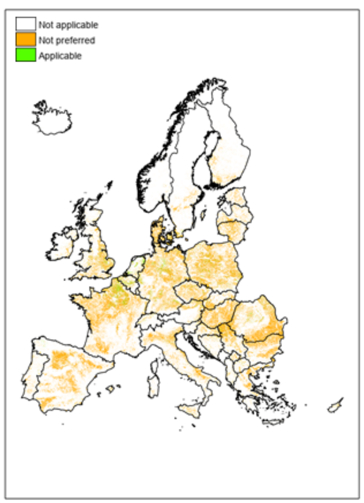
Precipitation
(classified for Underfoot fertilisation after CULTAN)
Europe

Slope
(classified for Underfoot fertilisation after CULTAN)
Europe

Soil depth
(classified for Underfoot fertilisation after CULTAN)
Europe

Landscape position
(classified for Underfoot fertilisation after CULTAN)
Europe

Land use
(classified for Underfoot fertilisation after CULTAN)
Europe

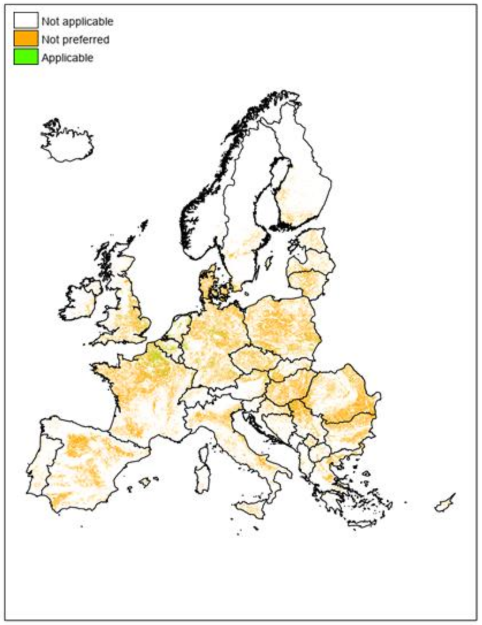


Aridity index
(classified for Underfoot fertilisation after CULTAN)
Europe

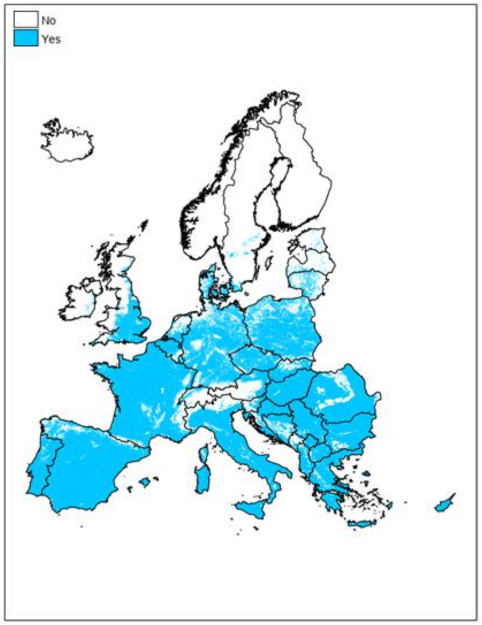
Soil texture
(classified for Underfoot fertilisation after CULTAN)
Europe

Soil fertility
(classified for Underfoot fertilisation after CULTAN)
Europe

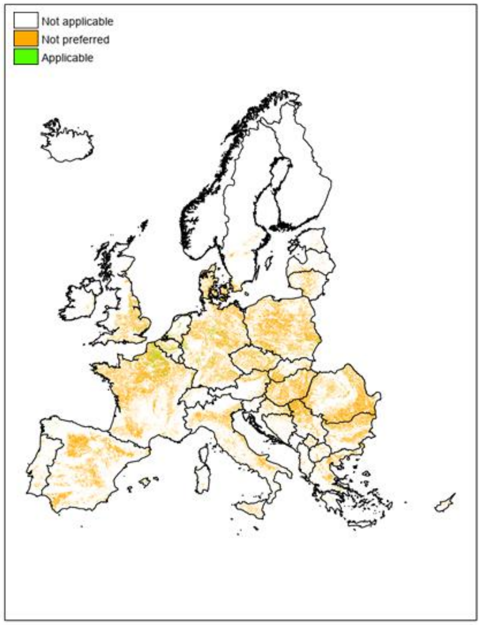
Overall applicability
Underfoot fertilisation after CULTAN
Europe



Relevance
Underfoot fertilisation after CULTAN
Europe



Combined
Underfoot fertilisation after CULTAN
Europe



3.1.22. Intercropping and minimum tillage

This SICS combines intercropping, the cultivation of two or more crops simultaneously on the same field, with minimum tillage to minimise or eliminate the reliance on glyphosate. The experiment in the Swiss study site included sugar beet, onions, and potatoes as main crops and large grain legumes, sunflower, phacelia and oats as green manure. After the growing cycle the green manure was left in the field.

Additional application and adoption factors:

Green manure plants should have low seed dispersion. Climate conditions should be favourable for green manure to grow after sowing. Furthermore, it is preferable that the green manure dies off before the cropping season. Therefore, the selection of the green manure (mix) should not be winter resistant. Options are amongst others phacelia, white mustard, summer vetch, and spring peas. Finally, a dry November-December period facilitates the soil tillage for the (superficial) incorporation of residues into the soil.

The slope should not be too steep for minimum tillage as this results in a considerable risk of overturning with a mounted seeder.

A medium level of expertise is required to apply the SICS correctly. Correct application is however critical for its success. The farmers need to know which green manure plants are desirable and which just lead to more work due to seed spreading etc. and decide on the right timing for the field interventions, which requires practice and experience.

In the long-term, benefits are expected to be higher compared to the conventional practice. However, it is easier to realise short term profits by using Glyphosate than by applying the SICS. However long-term effects on soil, human and animal health will be much better through application of the SICS.

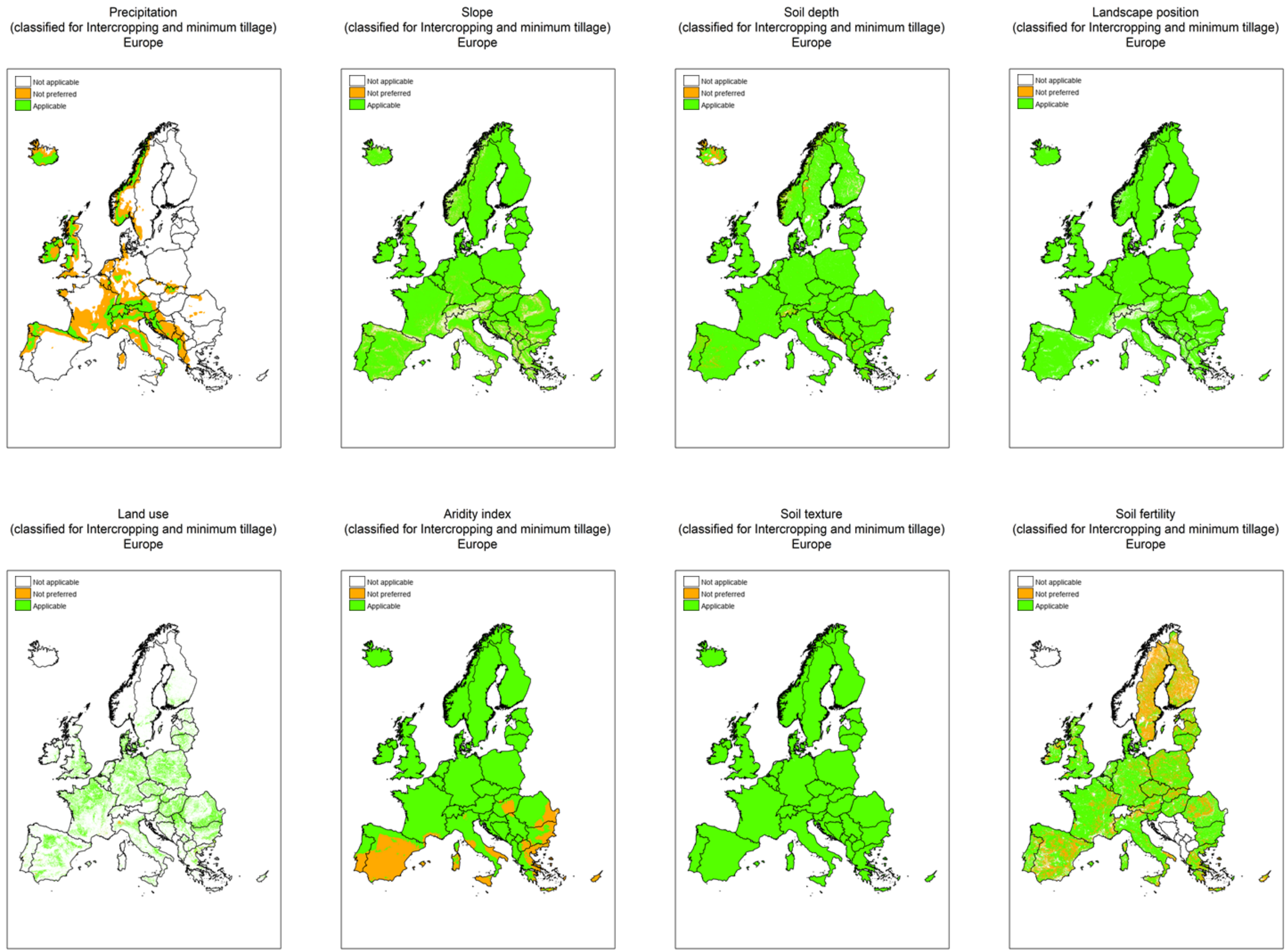
A main drawback of the SICS was the perceived risk that some plants or weeds might survive winter. This would negatively affect the quality and quantity of the following main crop.

The practices of some farmers are far removed from sustainable farming. There is, therefore, a need to encourage and support them in the transition away from pesticide use. It is, however, important to recognise that sustainable beet cultivation is not yet well established. In addition, pests can lead to a significant loss in yield. These considerations show that without concrete support such as subsidies, this task will be challenging.

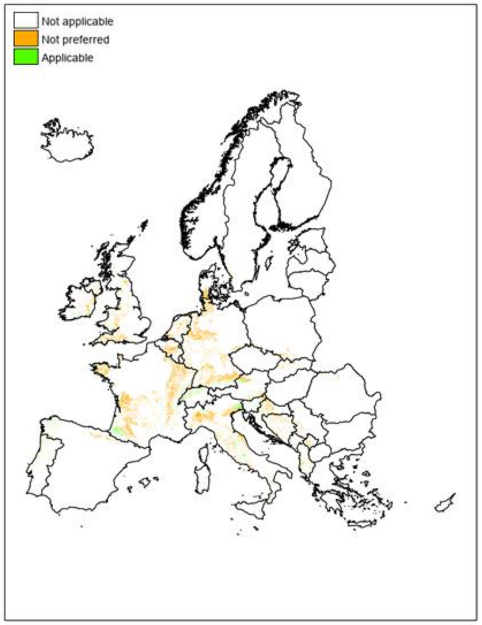
Early adopters who are able to demonstrate the effectiveness of the technique are likely to increase the uptake of the practice as this will help to increase the awareness and understanding.

Sources and more information:

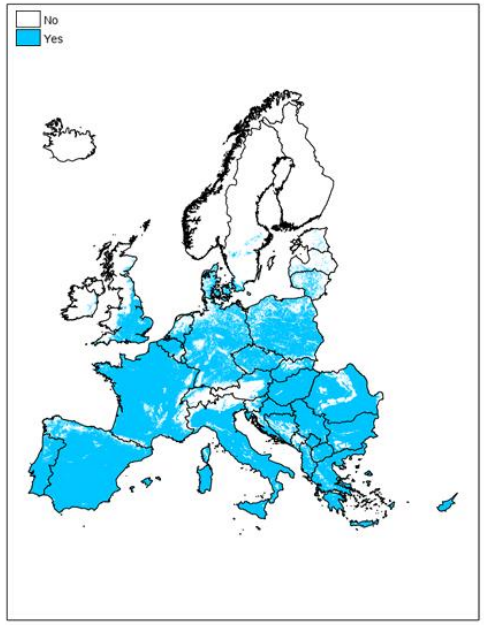
The WP4 & WP6 questionnaires, the fact sheet Switzerland: Green manures and minimum tillage for reducing glyphosate use and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.


Precipitation
(classified for Intercropping and minimum tillage)
Europe
Not applicable
Not preferred
Applicable
Slope
(classified for Intercropping and minimum tillage)
Europe
Not applicable
Not preferred
Applicable
Soil depth
(classified for Intercropping and minimum tillage)
Europe
Not applicable
Not preferred
Applicable
Landscape position
(classified for Intercropping and minimum tillage)
Europe
Not applicable
Not preferred
Applicable
Land use
(classified for Intercropping and minimum tillage)
Europe
Not applicable
Not preferred
Applicable
Aridity index
(classified for Intercropping and minimum tillage)
Europe
Not applicable
Not preferred
Applicable
Soil texture
(classified for Intercropping and minimum tillage)
Europe
Not applicable
Not preferred
Applicable
Soil fertility
(classified for Intercropping and minimum tillage)
Europe
Not applicable
Not preferred
Applicable

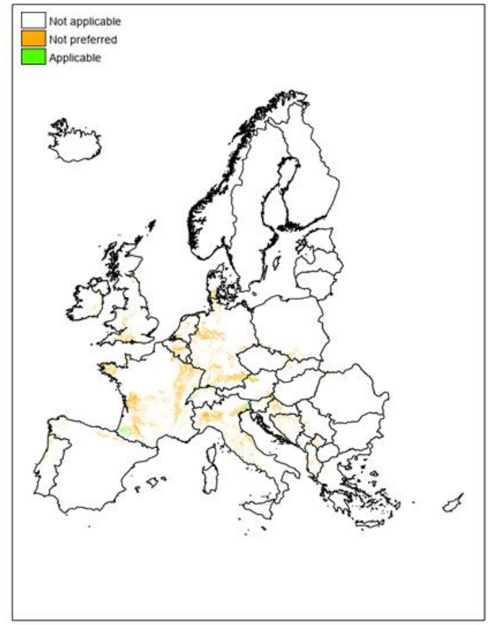
Overall applicability
Intercropping and minimum tillage
Europe



Relevance
Intercropping and minimum tillage
Europe



Combined
Intercropping and minimum tillage
Europe



3.1.23. Cover crops in spring cereals

Cover crops are often grown to prevent losses of nitrogen and protect the soil from erosion during autumn and winter. Certain cover crops can also be beneficial to soil carbon stocks, crop yields, physical properties and hydraulic properties. In the Norwegian study site the use of cover crops in spring cereals was investigated.

Additional application and adoption factors:

Cover crops can widely be applied across Europe, but conditions shouldn't be too dry if they are applied with rainfed agriculture. Good drainage might be useful for good crop development in the Nordic countries.

Especially in the Nordic countries, the length of the growing seasons and the related light limitation might impact on the applicability of the SICS.

The type of machinery required depends on whether the cover crop is spring sown, or autumn sown. In spring (usually species of grass or clovers): combine machine, grass seeder, harrow. In autumn (no grass species): centrifugal fertilizer spreader.

Based on the type of species of the cover crop, different additional conditions are relevant. For species that survive the winter it is common practice to terminate the growth in early spring as they might otherwise delay the next growing season and/or compete with the main crop. Freeze thaw cycles during winter might cause loss of phosphorus from the plants. In addition to the number of freeze-thaw cycles, this is impacted by snow cover and minimum freezing temperature.

A medium to low level of expertise is required to apply the SICS. Implementing cover crops is manageable. However, choosing the right species/mixtures requires good agronomic knowledge.

If the cover crop competes with the main crop, a decrease in crop yield makes it less profitable. However, choosing the right species would make the competition less prominent, and cover crops retaining nutrients and increasing soil organic matter can cause an increase in crop yield in the long run. Furthermore, legumes supplies N from the atmosphere, decreasing costs of fertilizers.

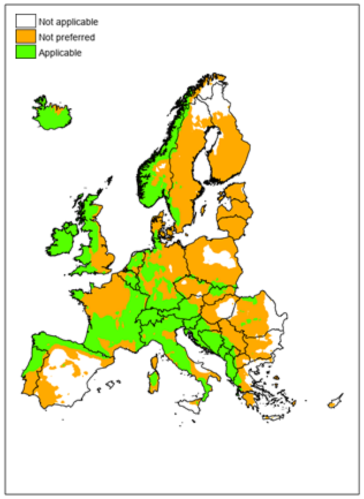
In the Norwegian study site where the SICS was tested, using cover crops has a strong positive economic impact, due in part to the subsidisation of cover crops through a regional environmental programme.

Key socio-economic factors that impact on the adoption include the political willingness and related availability of subsidies, the awareness of the technique together with its proven effectiveness, and the education and willingness of the farmer.

Sources and more information:

The WP4 & WP6 questionnaires, the fact sheet Norway: Cover crops for improving soil health and deliverables D5.3: Report on monitoring results and analysis and D7.2: Report on the selection of good policy alternatives at EU and study site level.

Precipitation
(classified for Cover crops in spring cereals)
Europe



Slope
(classified for Cover crops in spring cereals)
Europe

Soil depth
(classified for Cover crops in spring cereals)
Europe

Landscape position
(classified for Cover crops in spring cereals)
Europe

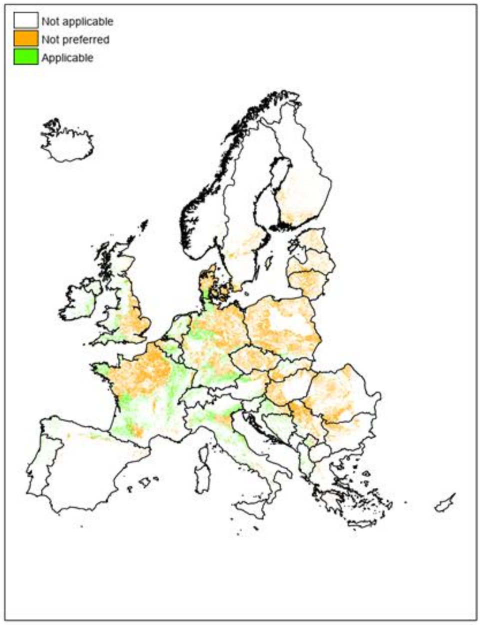
Land use
(classified for Cover crops in spring cereals)
Europe

Aridity index
(classified for Cover crops in spring cereals)
Europe

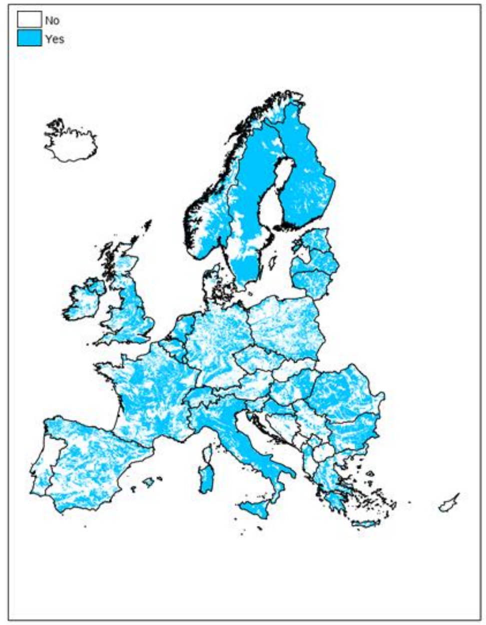
Soil texture
(classified for Cover crops in spring cereals)
Europe

Soil fertility
(classified for Cover crops in spring cereals)
Europe

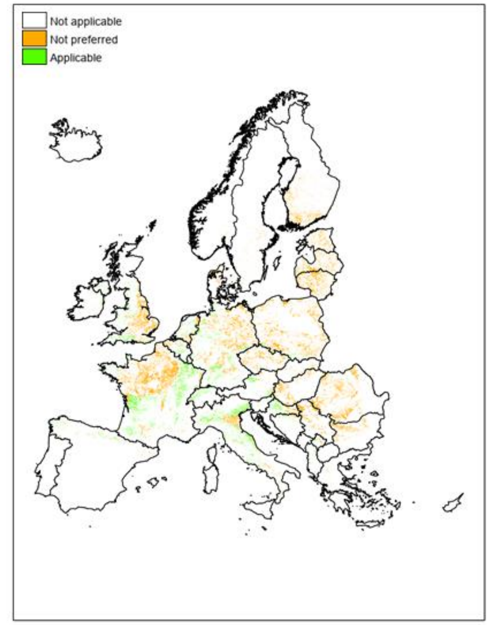
Overall applicability
Cover crops in spring cereals
Europe



Relevance
Cover crops in spring cereals
Europe



Combined
Cover crops in spring cereals
Europe



3.2. SICS Potential Index results based on applicability, relevance and impact

The following sections provide information on the example SICS per SICS category. For these SICS the full SICS Potential Index is calculated and hence information is provided on applicability, relevance and impact, with impact modelling being provided by the SoilCare IAM.

Factors found relevant for these SICS are presented in Table 3.2. As can be seen from the maps on the following pages, for this set of SICS we have applied the entire set of relevance factors. In the SoilCare IMT, the *Combined applicability/relevance* maps are also provided for each individual relevance factor.

For each SICS, first the *Combined applicability* and *Combined relevance* maps are shown, together with the *Combined applicability/relevance* map. Next, we show for each the sustainability (SOC, water erosion) and profitability (yield) aspect, the *SICS Potential per Indicator*. Combining all impacts, we then show the SICS Potential Index.

As discussed in Section 2 we furthermore calculate for each SICS the impact of key indicators: SOC, erosion reduction, yield, N leaching and runoff, and N-surplus. These are presented at the end of each section.

Table 3.2: Relevance factors per SICS. Factors with a bold ***X*** *are found most relevant for SICS application.*

	Wind erosion	Water erosion	Soil compaction	Organic matter content	Soil micro-organisms at risk	Soil fauna at risk	Biological functions at risk
Cover crops	X	X	X	X	X	X	X
Mulching	X	X		X	X		X
Compaction alleviation			**X**				
Minimum tillage	**X**	**X**	**X**			**X**	**X**

3.2.1. Cover crops

Cover crops are non-harvested crops grown in between two main crop seasons, mainly intended to protect the structural aspects of soil fertility and reduce erosion. Cover crops can be applied in combination with arable and permanent crops. They can be incorporated into the soil as green manure thereby adding nutrients and organic matter to the soil.

Additional application and adoption factors:

Although cover crops can be applied throughout Europe under different climate, soil and land use conditions as can be seen in the applicability maps below (Figure 3.2), the selection of cover crops needs to match with the local conditions, making good agronomic knowledge important in the application of this SICS.

Throughout Europe different limitations might impact on the application of cover crops. In the northern countries the length of the growing season and related light limitation might limit the application of the SICS. In drier areas, competition for water with the main crop might be of concern and ensuring the crop is killed before the main crop is planted can be critical for successful application. Depending on the climate conditions (winter temperatures, frost) and selection of cover crop, herbicide might be needed to do so.

After a conversion time of likely a few years, this SICS could reduce production costs, while maintaining high yields according to field trials and understanding of those working in the field. Model results are more positive and indicate a likely increase of yields over time (see the SICS Potential Index results section below and Figure 3.5. Financial incentives at the start would therefore increase the uptake. It should be noted that the economic outcomes of this SICS are likely varying depending on weather conditions.

Factors encouraging the adoption of this SICS include reduced need for fertilisers and biodiversity enhancement. Key socio-economic aspects listed as important for the adoption of the SICS include: financial capability of the farmer to implement the technique without support, availability of subsidies, willingness of the farmer, political willingness, awareness and understanding of the technique, application of the technique by peers, proven effectiveness of the technique, and the education level of the farmer (or person implementing the technique). Furthermore, having a successor and legislative requirements are expected to facilitate the adoption too.

Barriers listed to prevent the adoption include the cost of seeds, insufficient knowledge about the practice and the complexity of the practice.

SICS Potential Index results:

As mentioned above, cover crops can widely be applied across Europe. Looking at the applicability maps there are areas that require some special consideration (e.g. the areas is the south of Europe as can be shown in the Aridity index in Figure 3.2), but this could be overcome due to a careful selection of crops and appropriate management (i.e. timely elimination of the cover crop to avoid competition for water with the main crop, use of irrigation where needed). Cover crops could be used to mitigate a range of soil threats and improve soil conditions, as can be seen in Figure 3.3. When all relevance aspects are considered together, we see that almost all over Europe it would be relevant to apply cover crops. Looking at the impacts on yield, SOC and erosion control we see medium to high impacts across large parts of Europe, especially in the northern part, indicating that cover crops are likely to be both profitable and sustainable. The above results in a positive SICS potential for all indicators (yield, SOC and erosion control) (see Figure 3.6) and hence a positive SICS Potential Index (see Figure 3.7).

Regional impacts also show benefits of applying cover crops. The strongest yield increases are expected in the south of Europe, but also in England, Denmark, the northern parts of Germany and Poland and Finland, substantial increases are expected. SOC and erosion improvements are also expected in these areas as well as in Hungary, Slovakia, the Czech Republic and north-west France. Reduction of N leaching and reduction of soil N surplus are expected to be the largest in the east of Europe and central Spain. This is because the potential implementation is much higher in these regions, as the current use of cover crops is low, whereas in regions with a high N surplus there is already obligatory use of cover crops.

Sources and more information:

Several SoilCare study sites have investigated specific cover crops as (part of) their SICS, namely the German, Italian, Polish, Spanish, Danish, Swiss, and Norwegian study sites. Information on applicability and relevance, as found for these experiments, is provided in Section 3.1.

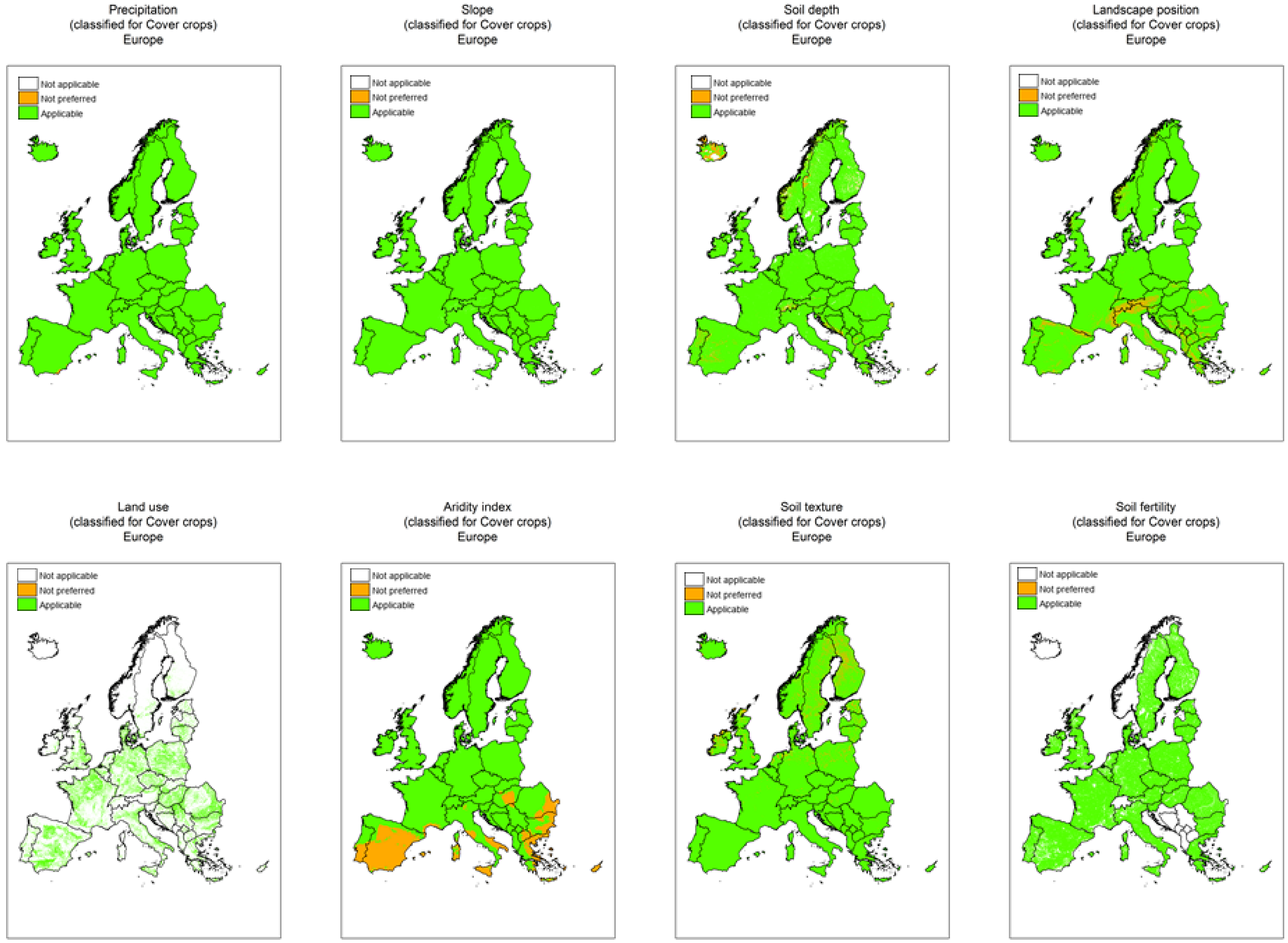


Figure 3.2: Applicability maps for cover crops. Note that for countries with no data values in any of the maps, the applicability based on that factor is omitted

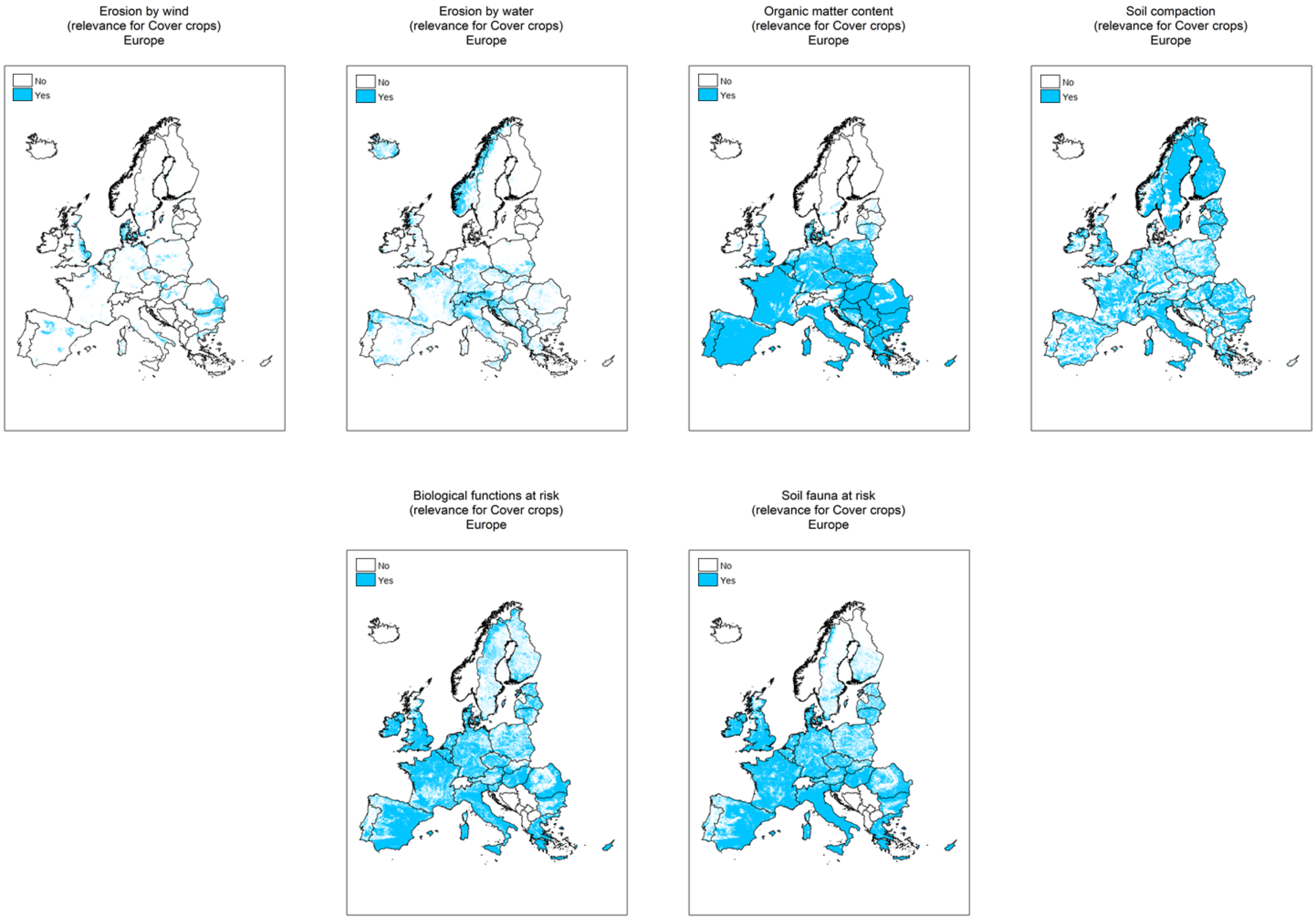


Figure 3.3: Relevance maps for cover crops

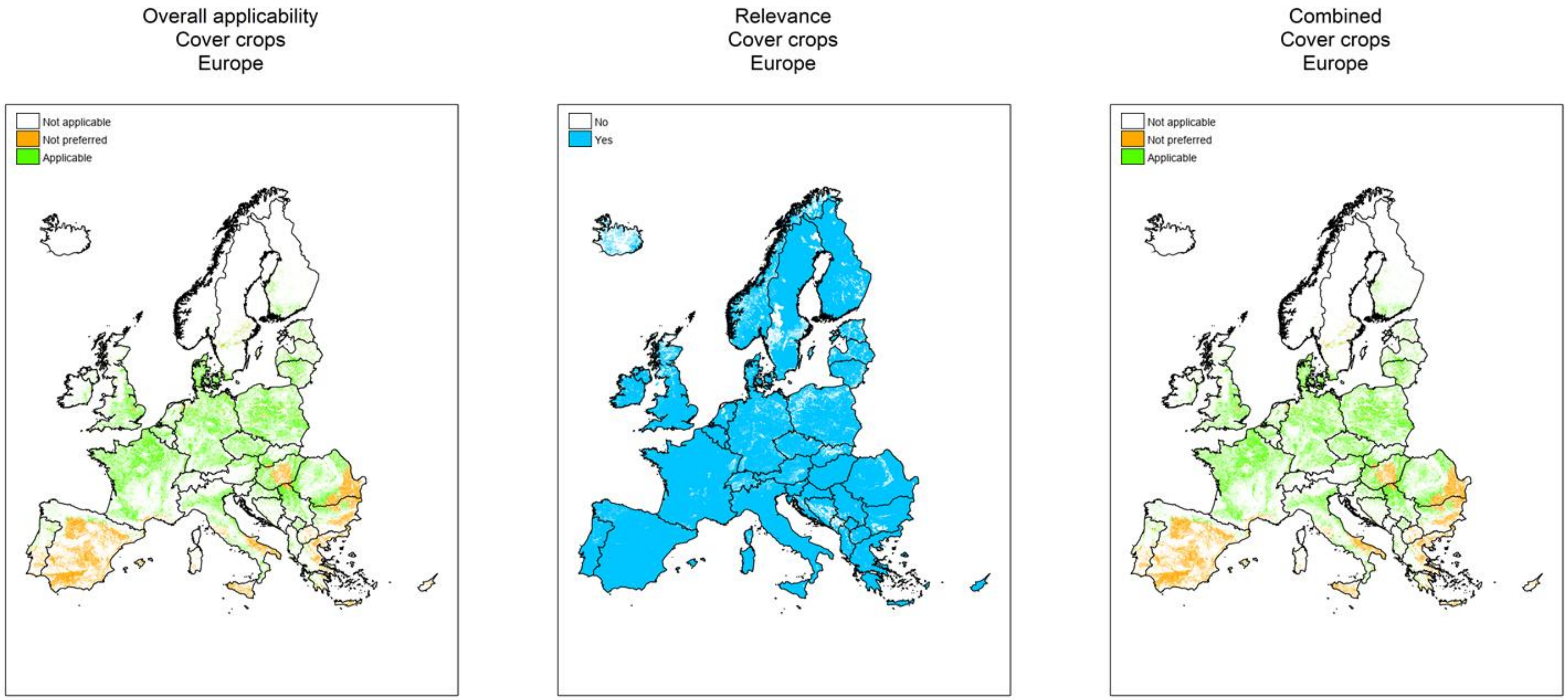


Figure 3.4: Overall (combined) applicability (left), overall (combined) relevance (center) and combined applicability / relevance (right) for cover crops

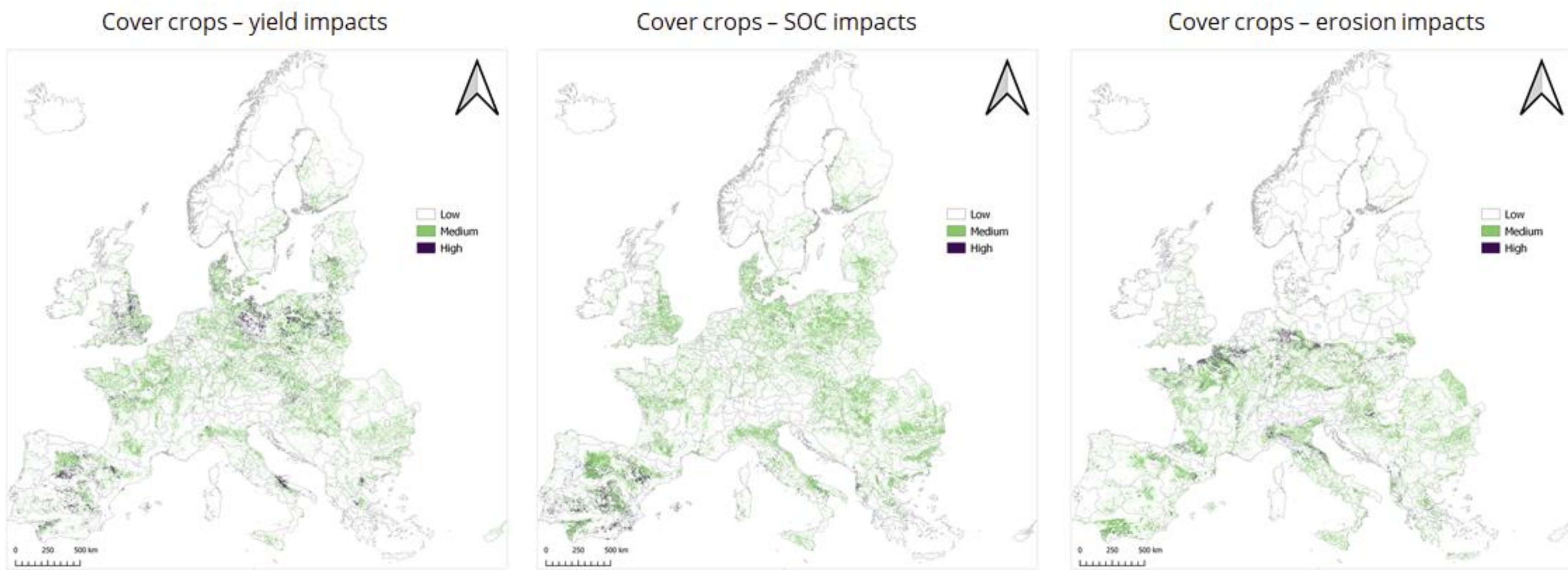


Figure 3.5: Impact of cover crops vs no measures on yield (left), SOC contents (center) and erosion reduction (right)

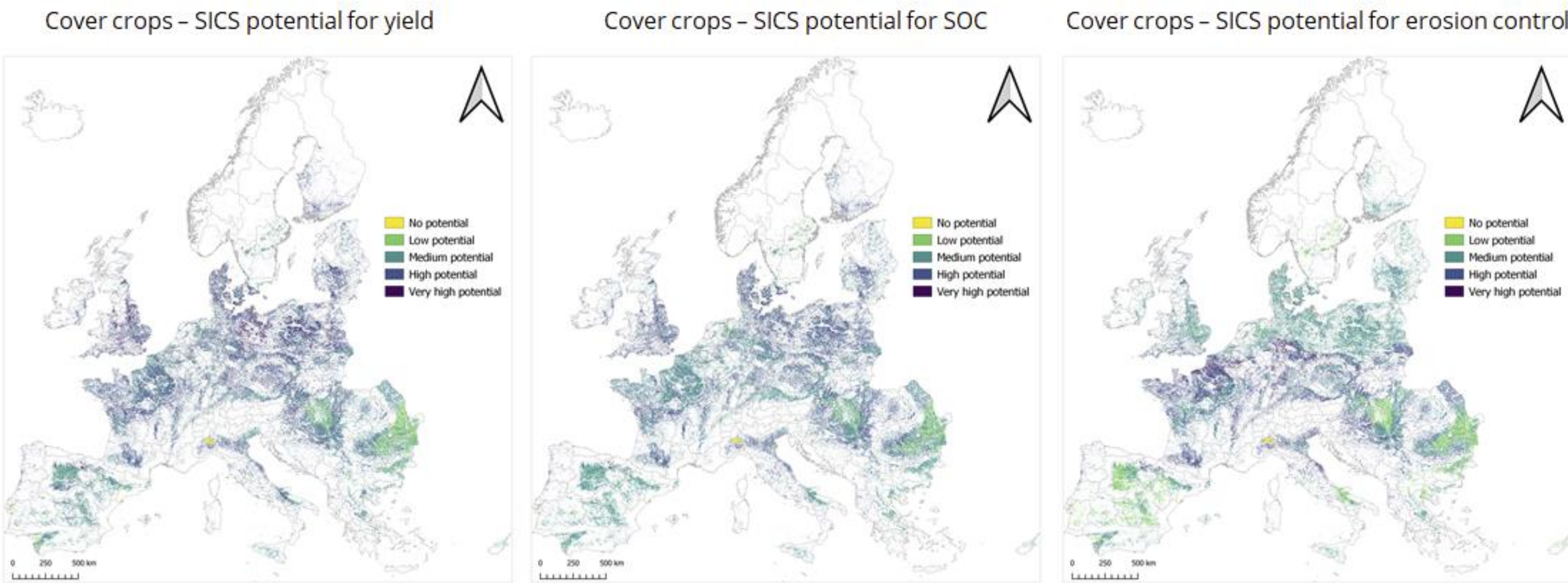


Figure 3.6: SICS potential (cover crops) for yield (left), SOC contents (center) and erosion control (right)

SICS Potential Index – Cover crops

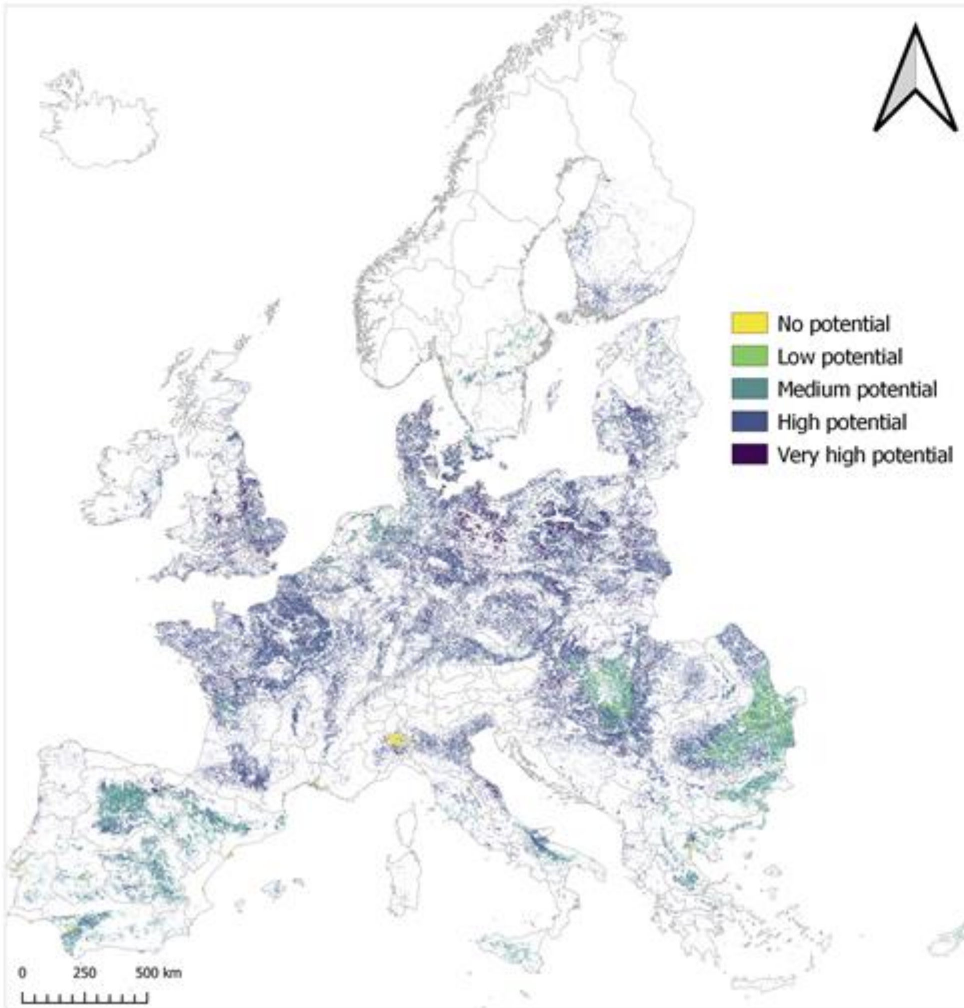


Figure 3.7: SICS Potential Index for cover crops

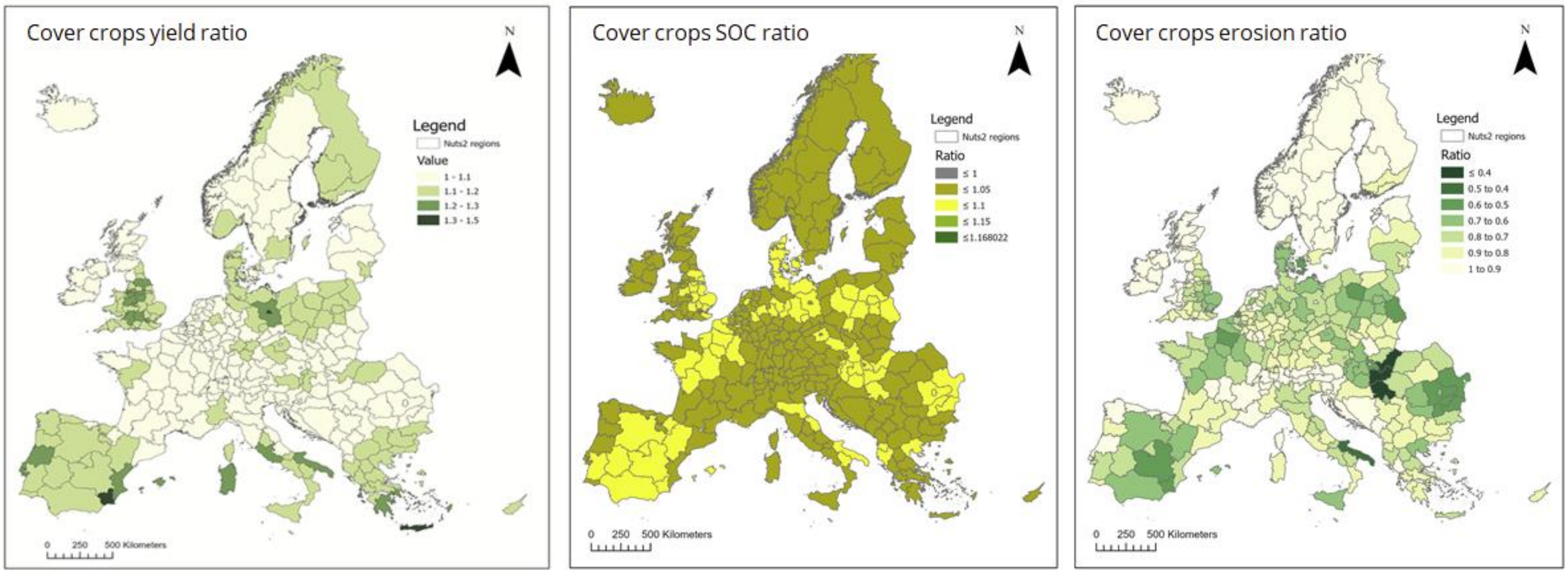


Figure 3.8: Relative impact of cover crops vs no measures on production (left), SOC sequestration (center) and erosion reduction (right) per NUTS-2 region

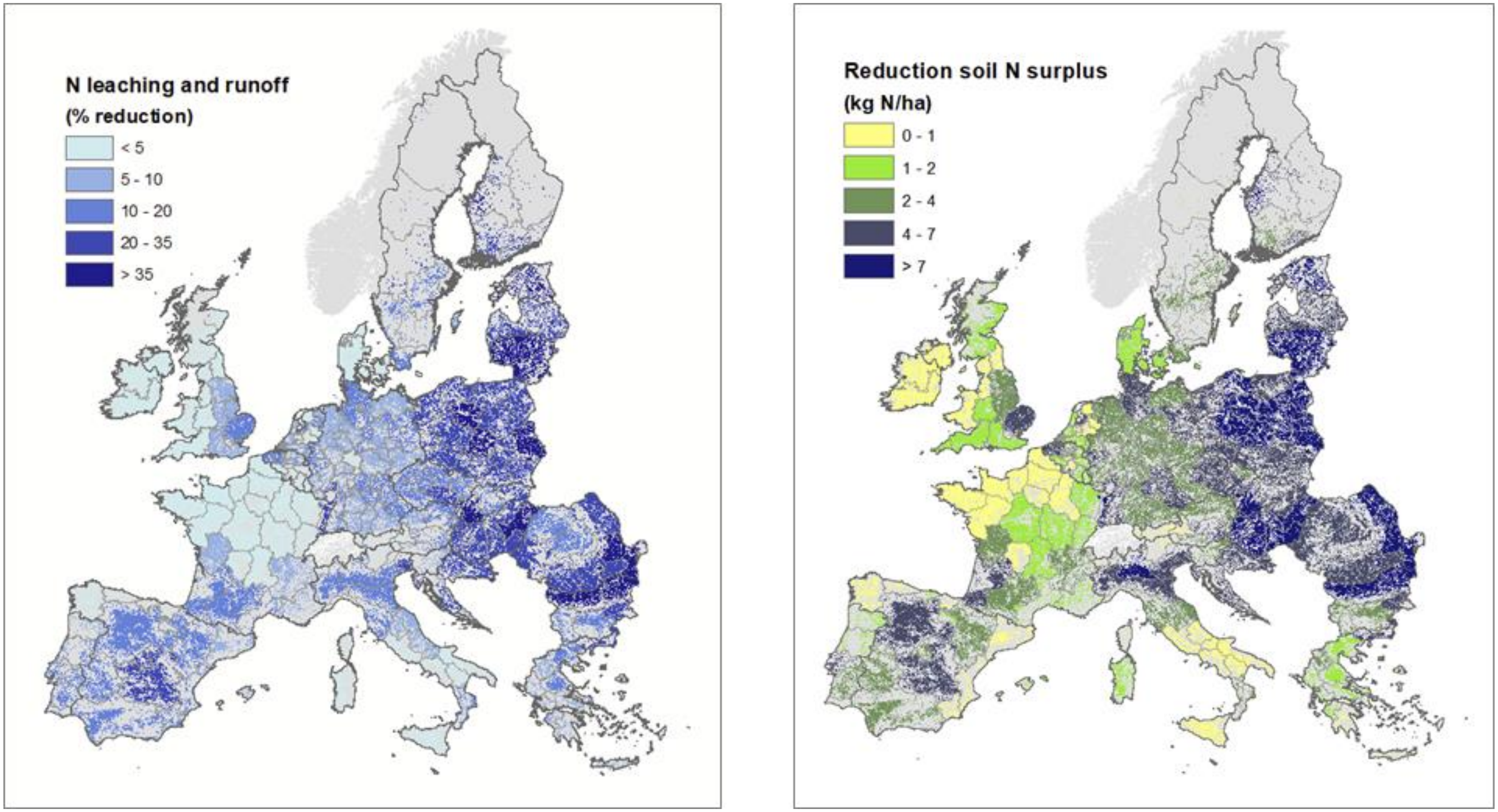


Figure 3.9: Relative impact of cover crops vs no measures on N leaching and runoff (left) and soil N surplus (right)

3.2.2. Mulching

Mulching is the application of various types of dead plant material on the soil surface. Mulch material consists mainly of straw mulch or pruning residues, but also wood chips are used (e.g., in the Belgian study site). The main purpose is to cover the soil to protect it against erosion, to provide moisture (by reducing evaporation from bare soil), increase local soil temperature and add organic material to the soil. Mulching can be applied in annual crops between harvest and sowing and in perennial crops, e.g., between tree or vine grape rows.

Additional application and adoption factors:

One of the most important limitations for applying mulching is the availability of mulching material. In southern Europe, pruning residues from e.g., olive and almond cultivation are available, as is the case for e.g., fruit tree cultivation in most of Europe. Straw mulch would be available when cereal cultivation is practiced nearby. Where mulching material is not available on the field or nearby, the costs of obtaining mulching material is another concern for the adoption of this SICS. The effect of mulching depends on the amount of mulching material applied. If locally available material is limited, the effect of mulching will be reduced accordingly. In addition, the legal restrictions regarding the use of mulch material from a source outside of the field or farm could be a key barrier for uptake of the SICS.

As with other SICS, the experience and knowledge of the farmer is a factor for the uptake of this SICS.

SICS Potential Index results:

Application of mulching has almost no limitations as it can be applied under most pedo-climatic conditions and with almost all crop types (see Figure 3.10). It also has a high relevance for application, as it can be used to mitigate water and wind erosion and increase SOC and hence support the soil biology. These considerations are reflected by the maps presented in Figure 3.12. Increases in yield and SOC are especially expected in areas that currently have low SOC values, but we also see high yield increases in the UK, Denmark, and the northern parts of Germany and Poland. Medium yield impacts can be found throughout large parts of Europe. The highest erosion impacts are expected in areas prone to erosion, such as the loss belt and the Apennines (see Figure 3.13). Resulting from the above, also the SICS potential for yield, SOC and erosion are high across many parts of Europe, as is the overall SICS Potential Index, with the exception of Scandinavia. This is partly because there are not so many agricultural areas, but also because the relevance is low (e.g., high SOC levels and low erosion risk). These findings could be due to the scale at which the modelling is applied, and hence more regional modelling would be required to further understand this.

Looking at the aggregated impacts at NUTS-2 level, positive profitability and sustainability impacts are to be expected all over Europe with regional aggregates in Figure 3.16 reflecting the local, grid-cell information from Figure 3.14.

Sources and more information:

The Belgium SoilCare study site has investigated mulching, see information provided in Section 3.1. Additional information can be found in the literature based on the meta-analysis of research conducted in China and elsewhere, e.g., Cheng et al. (2020), Gao et al. (2019), Li et al. (2018), Lu (2014), or Lin et al. (2018).

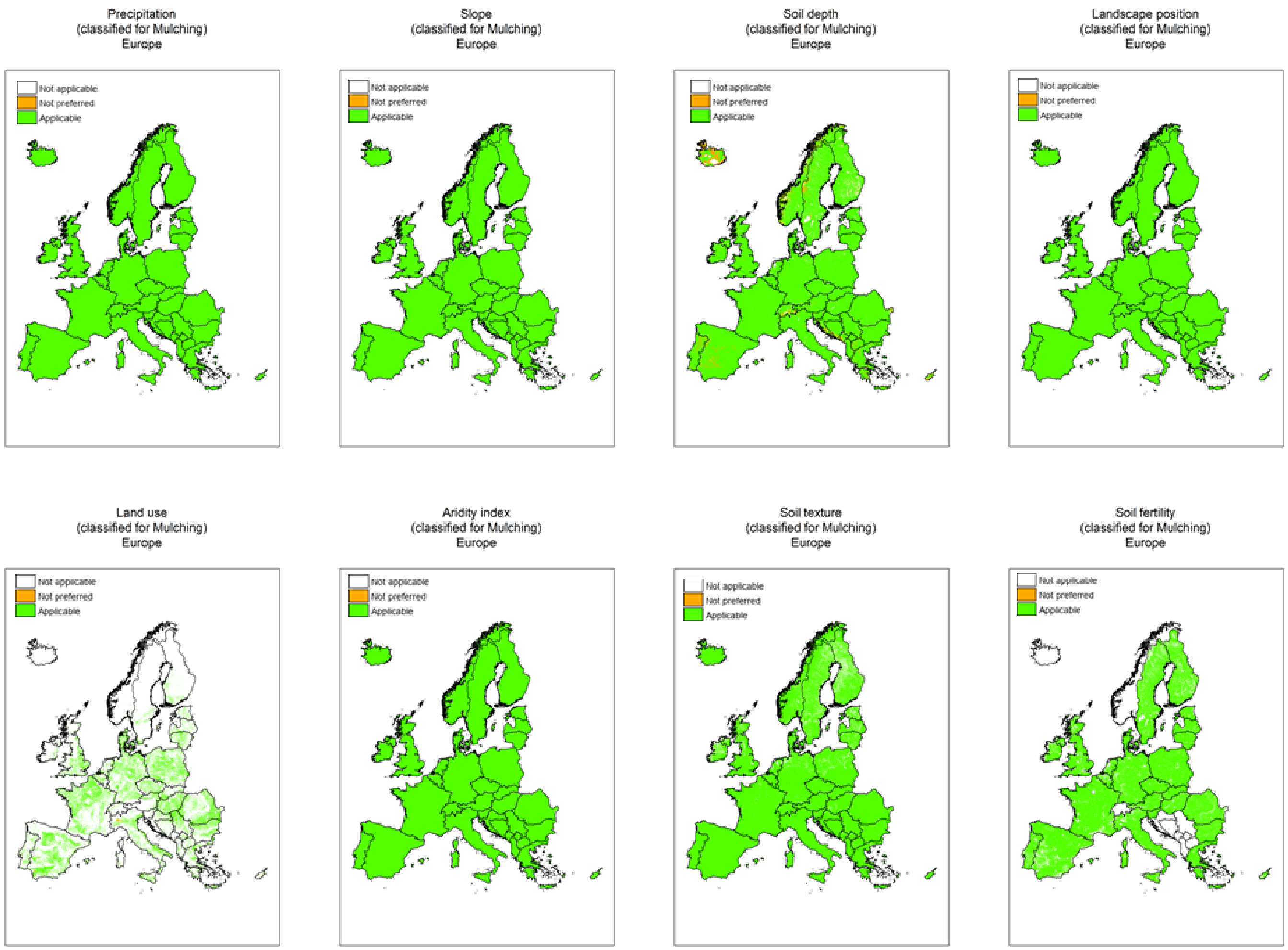


Figure 3.10: Applicability maps for mulching. Note that for countries with no data values in any of the maps, the applicability based on that factor is omitted

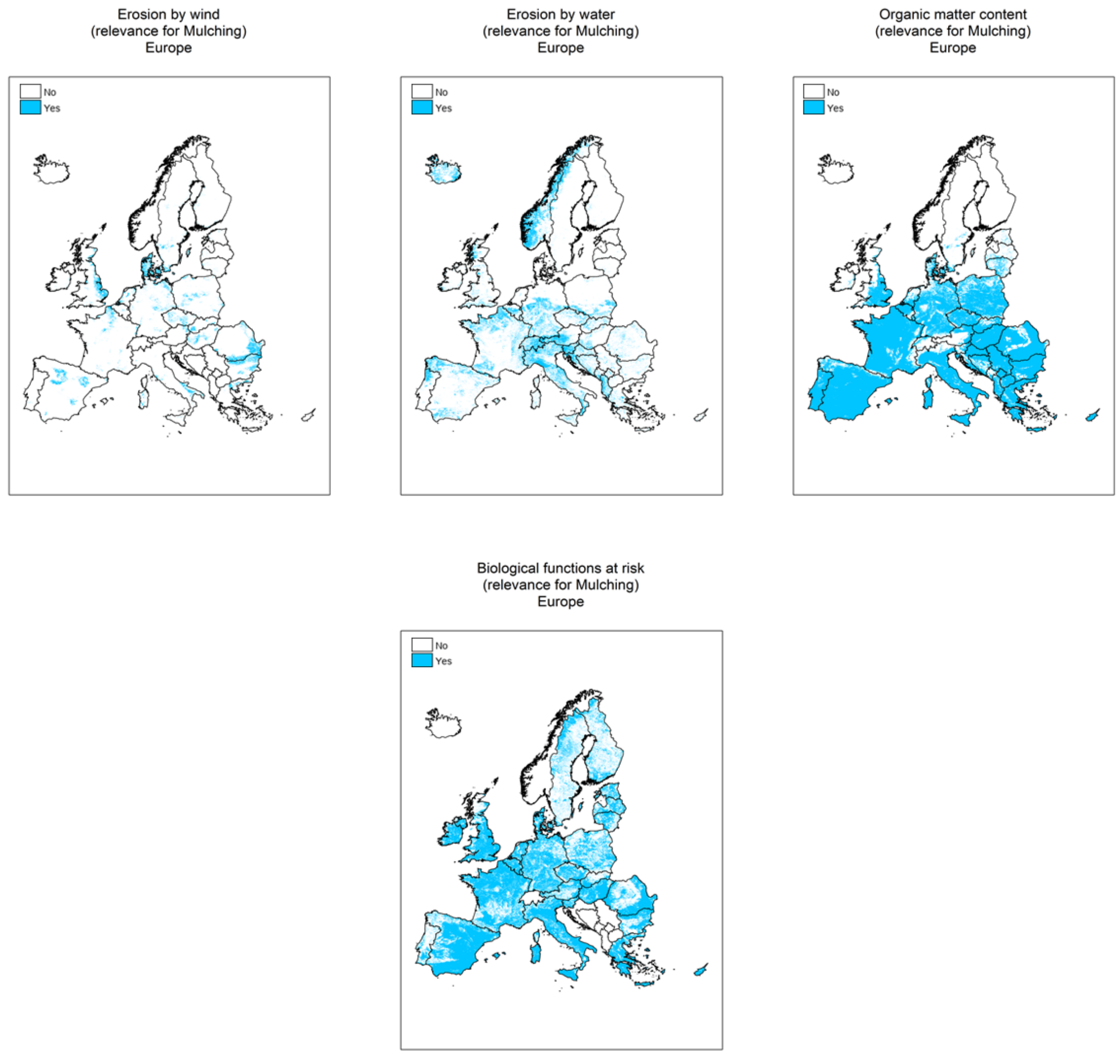


Figure 3.11: Relevance maps for mulching

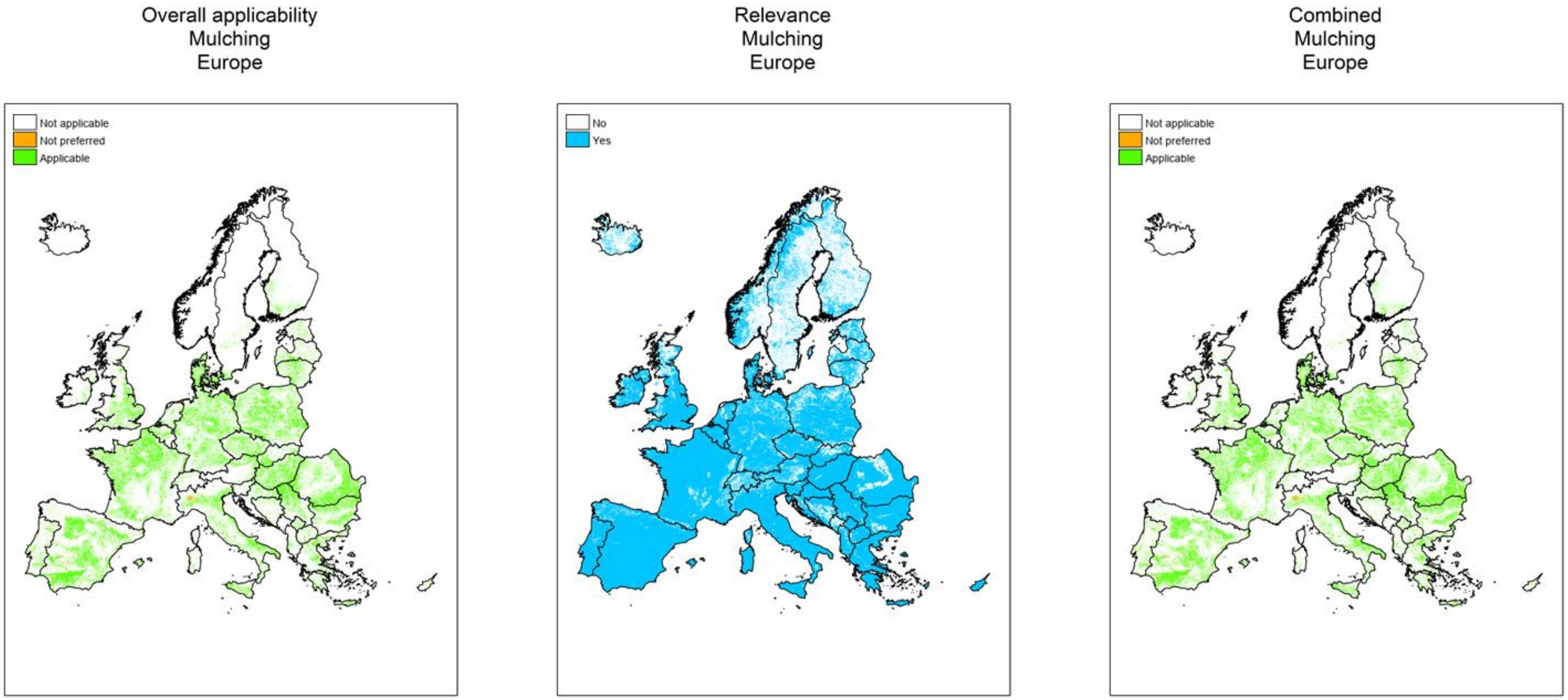


Figure 3.12: Overall (combined) applicability (left), overall (combined) relevance (center) and combined applicability / relevance (right) for mulching

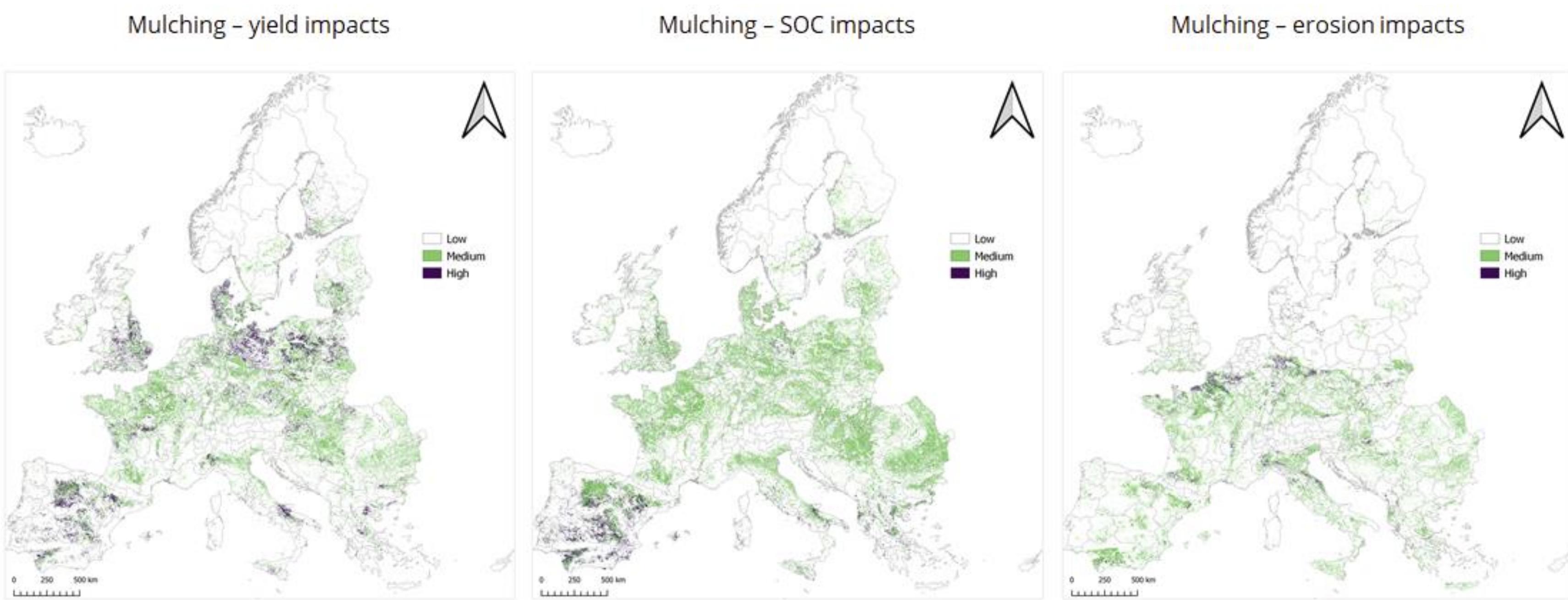


Figure 3.13: Impact of mulching vs no measures on yield (left), SOC contents (center) and erosion reduction (right)

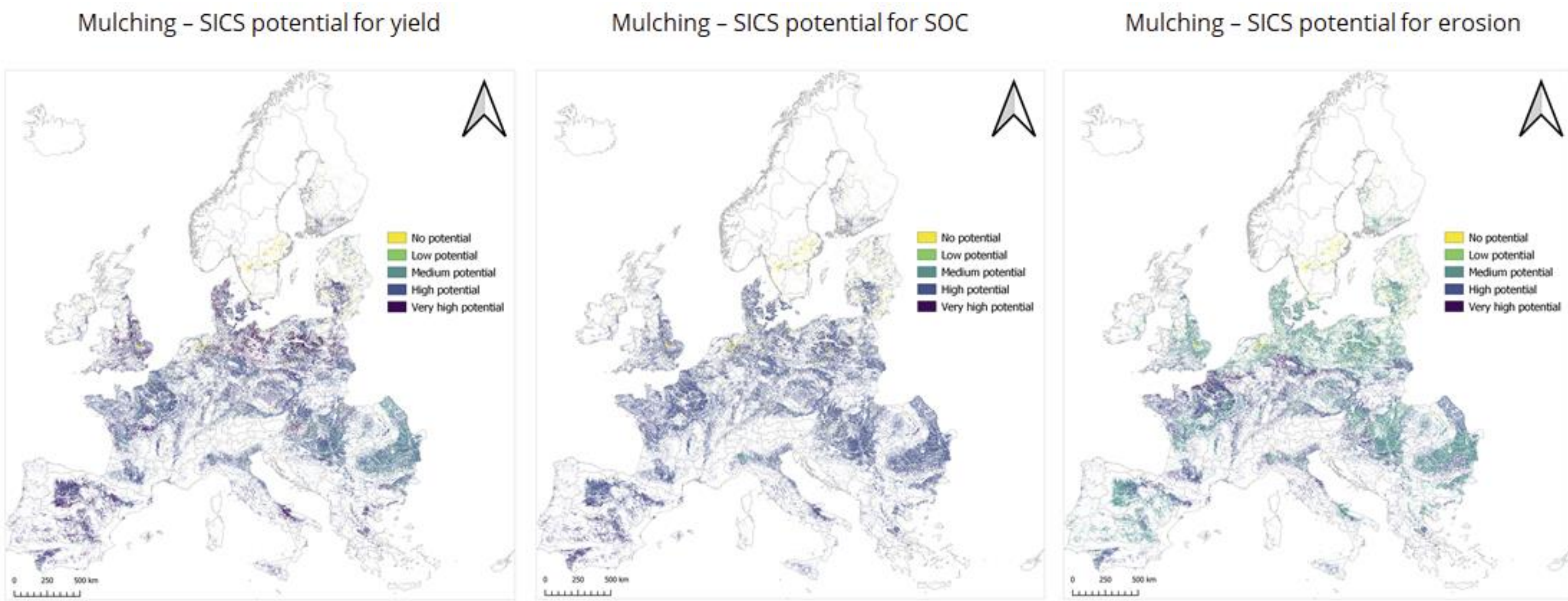


Figure 3.14: SICS potential (mulching) for yield (left), SOC contents (center) and erosion control (right)

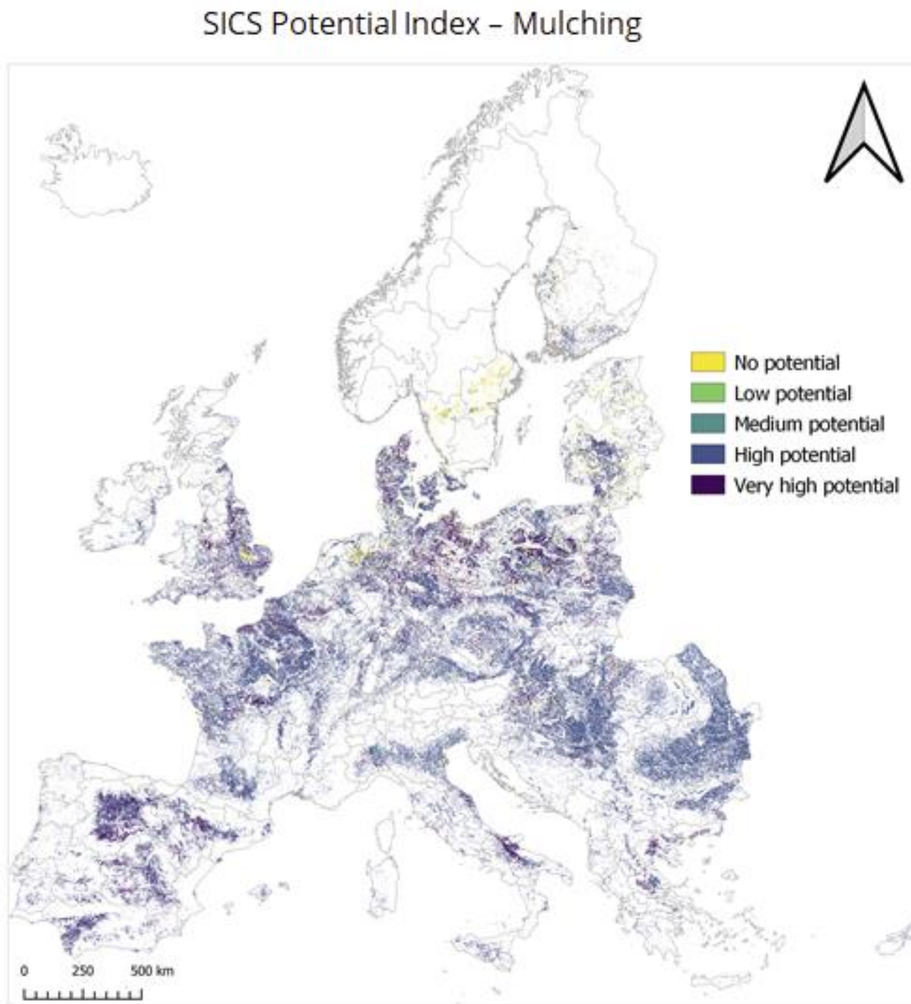


Figure 3.15: SICS Potential Index for mulching

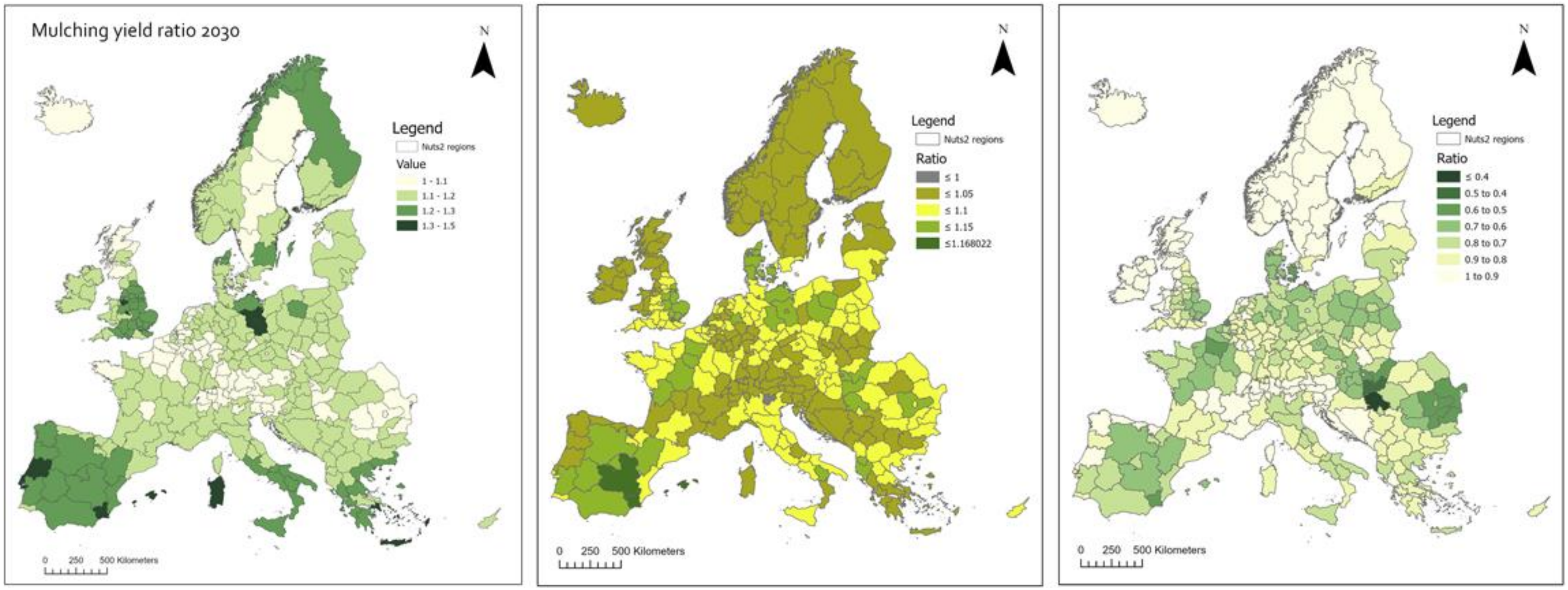


Figure 3.16: Relative impact of mulching vs no measures on production (left), SOC sequestration (center) and erosion reduction (right) per NUTS-2 region

3.2.3. Minimum tillage

Minimum tillage aims to minimize the frequency or intensity of tillage operations with the aim to have minimum soil disturbance, which is beneficial for soil structure. It is a technique that does not turn the soil over, compared to intensive tillage which changes the soil structure using ploughs. By minimizing tillage operations, the soil experiences less pressure on the surface from heavy machinery, preventing further compaction. Minimum tillage can, especially in combination with plant residues on the soil surface, reduce water and wind erosion, evaporation, and warming of the soil in summer and autumn. The latter two result in higher humidity of the soil which can lead to better conditions for the emergence of winter crops. In addition, minimum tillage can mitigate the decline in soil organic carbon compared to conventional ploughing.

Additional application and adoption factors:

As is shown in the maps below, minimum tillage can be widely applied across Europe (green and brown categories on the map) but might not be preferred in some areas because of soil depth and texture.

Depending on the specific implementation of the practice, several advantages and disadvantages can be listed. In some cases (less frequent, less deep tillage) no new equipment is required, while in other cases equipment such as a no-till seed drill is needed (Italian study site). For the applications where new equipment is needed the technique might find better uptake at larger farms.

In the Czech study site, the SICS resulted in a higher nutrient immobilization in the soil in the tilled surface layer. This required the application of calcium (or magnesium) to maintain a good soil structure and related water infiltration into the soil. Growing catch crops and liming can help to ameliorate this issue.

This SICS is expected to have a positive benefit/cost ratio due to the reduced tillage cost. Because it might take a few years for yields to return to normal levels and to facilitate the transition, financial incentives in the introduction period would facilitate the uptake of this SICS.

Expected future legislative requirements and/or subsidies depending on carbon storage in the soil will also facilitate adoption of this SICS.

Understanding and proven effectiveness of the technique are critical for its adoption. Furthermore, the willingness of the farmer and the availability of subsidies (together with the financial capability of the farmer) are likely to stimulate its uptake.

SICS Potential Index results:

Although this technique can be widely applied across Europe, there are large areas where special consideration is required due to the slope, soil depth and soil texture, indicated as 'not preferred' on the applicability maps (Figure 3.17). Looking at the benefits to SICS could bring in mitigation soil threats and improving soil conditions (Figure 3.18) it would be relevant to apply the technique almost everywhere in Europe. So although relevant, and possible to be applied across Europe, special consideration is required in many locations as indicated in the combined applicability/relance map in Figure 3.19.

The modelling indicates that erosion control would be a key benefit of this technique. Yield impacts seem minor throughout most of Europe, which concurs with the literature. However, a note of caution on the SOC results is required because of the level of abstraction of the modelling. It would therefore be good to further explore this.

The rather low impacts in yield and SOC as well as the high erosion impacts are all reflected in the SICS potential for yield, SOC and erosion control, with the SICS potential for erosion control clearly being the highest. Combining the high relevance, the applicability status (application possible but with some considerations in most areas), the rather low yield and SOC impacts and the high erosion impacts, the overall SICS Potential Index indicates a low, to medium to high potential across Europe.

Regional impacts reflect the local impacts, with small positive impacts expected for production and SOC sequestration and substantial impacts for erosion control.

Sources and more information:

Several SoilCare study sites have investigated specific tillage practices as (part of) their SICS, namely the German, Italian, Czech, Greek, UK, and Swiss study sites, see information provided in Section 3.1.

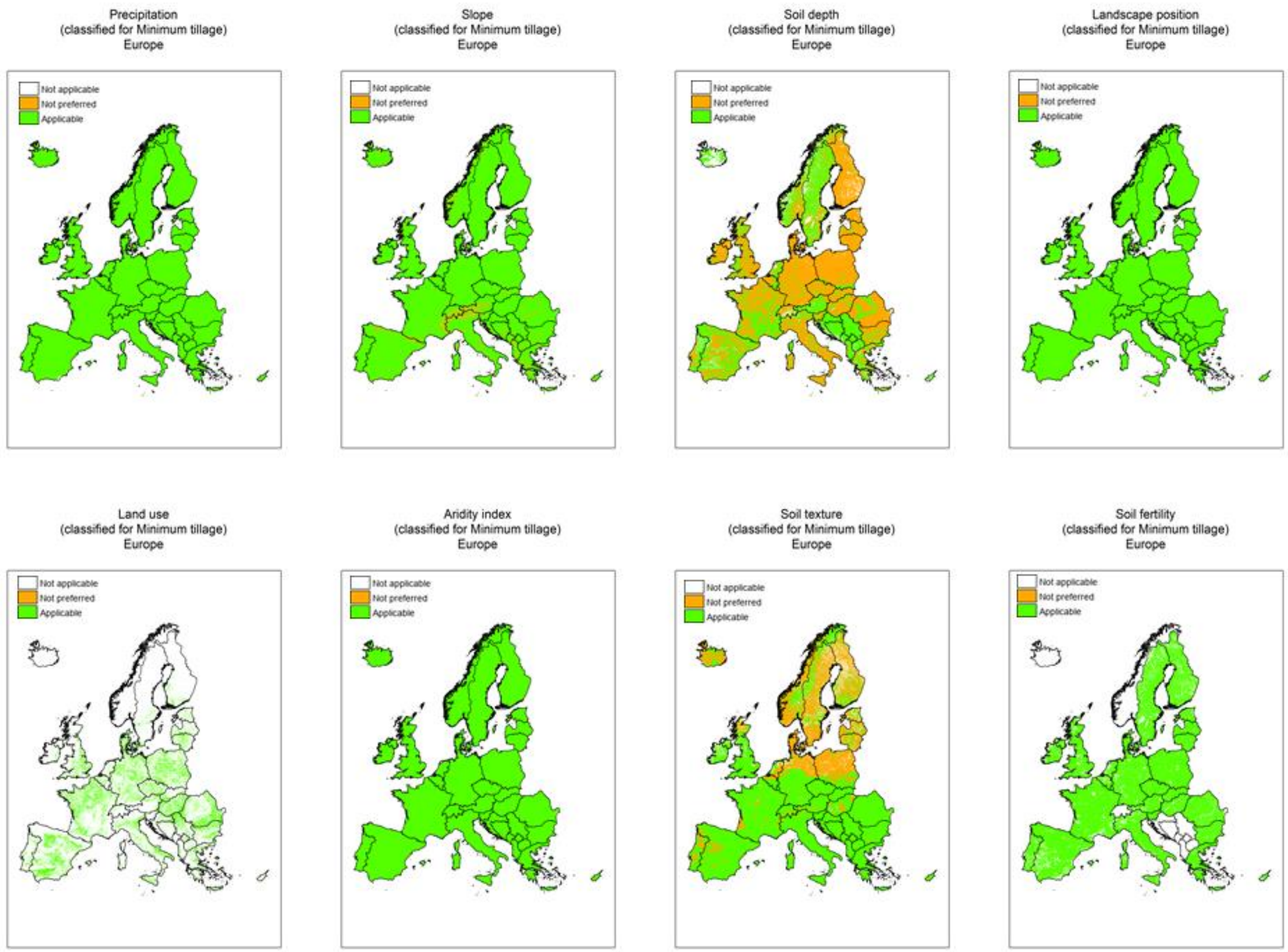


Figure 3.17: Applicability maps for minimum tillage. Note that for countries with no data values in any of the maps, the applicability based on that factor is omitted

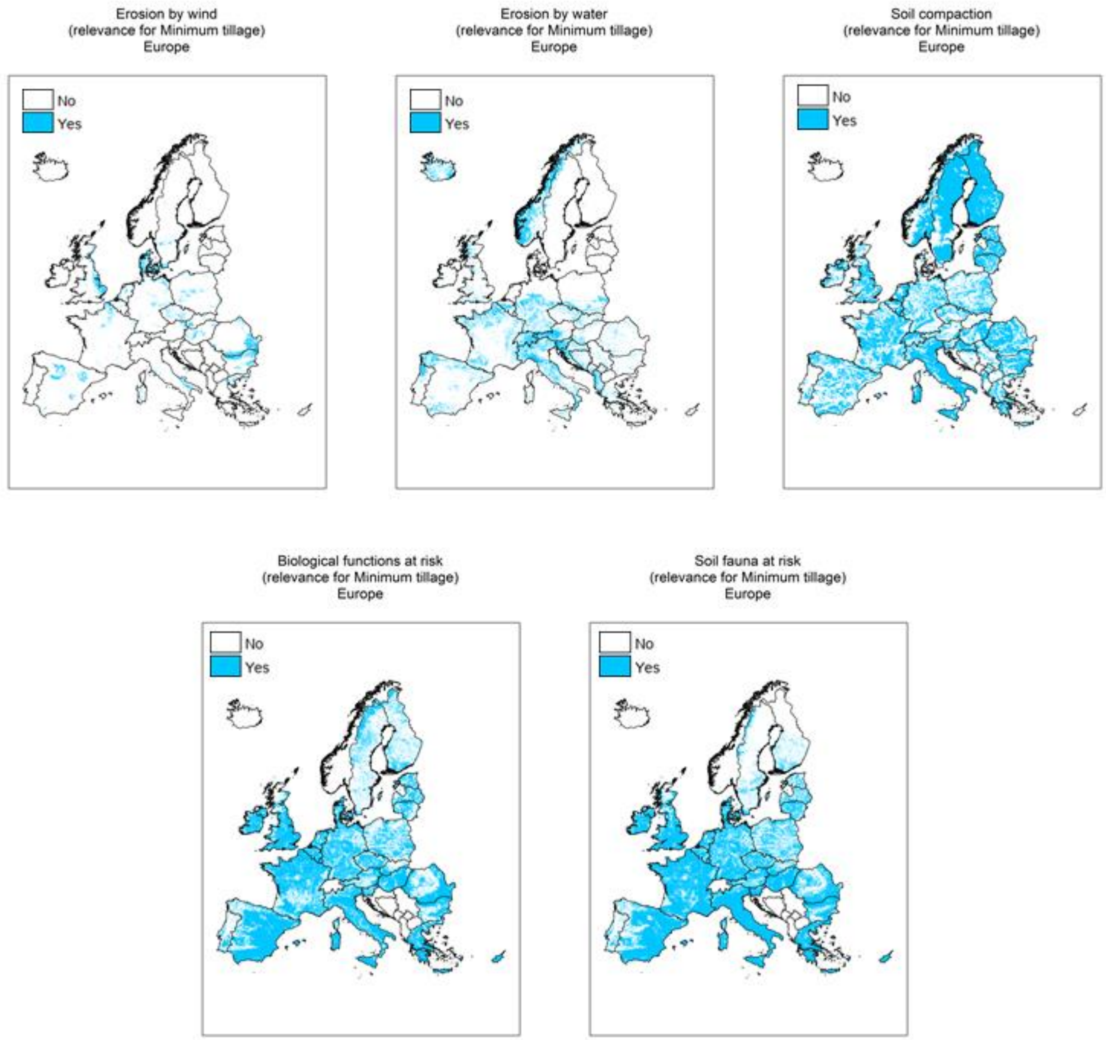


Figure 3.18: Relevance maps for minimum tillage

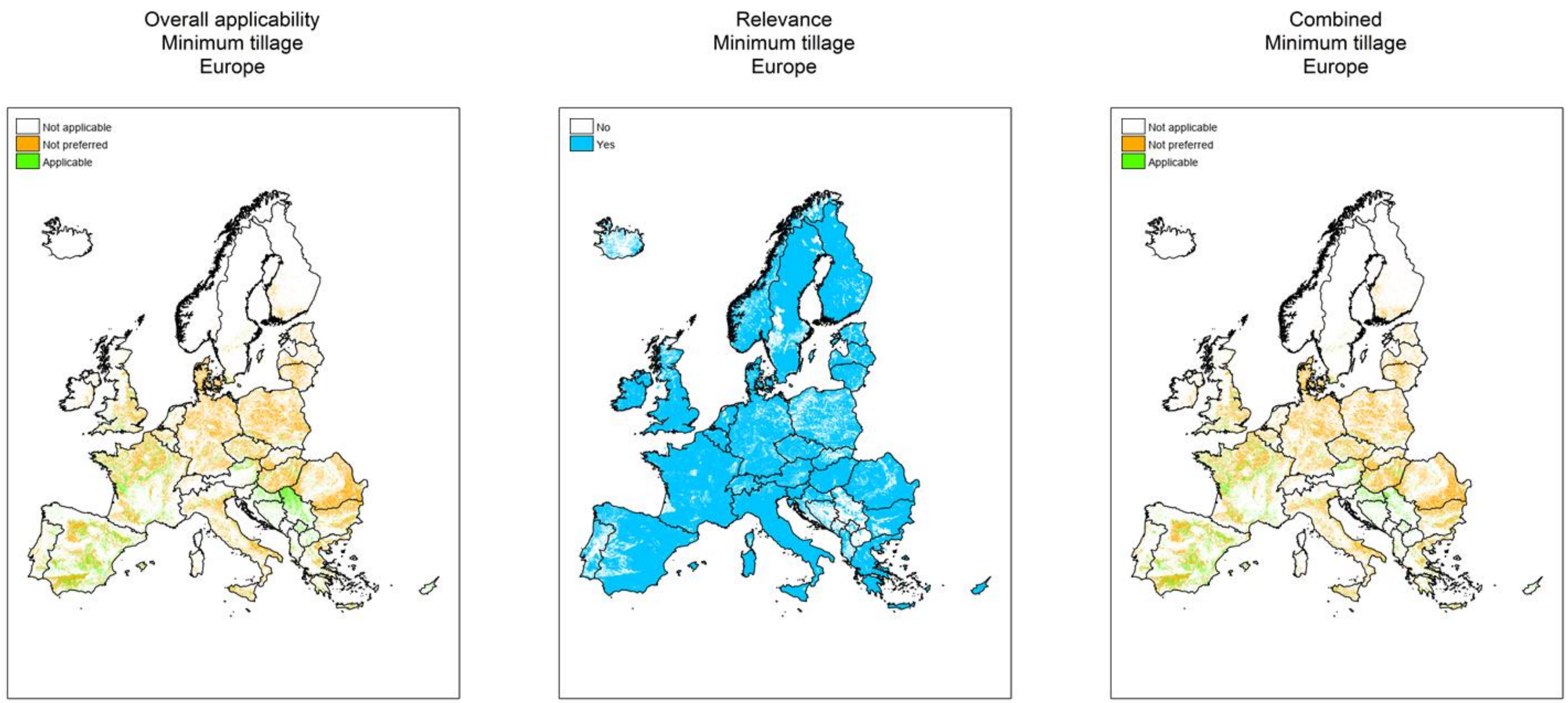


Figure 3.19: Overall (combined) applicability (left), overall (combined) relevance (center) and combined applicability / relevance (right) for minimum tillage

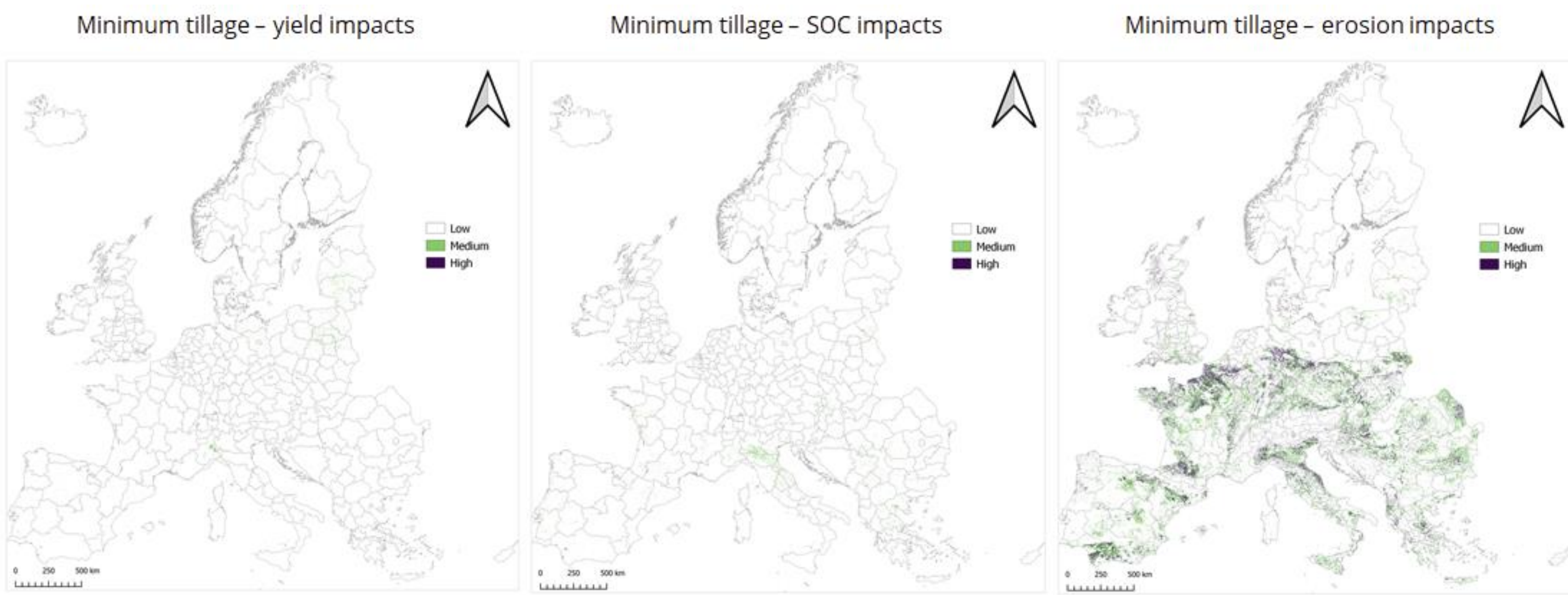


Figure 3.20: Impact of minimum tillage vs no measures on yield (left), SOC contents (center) and erosion reduction (right)

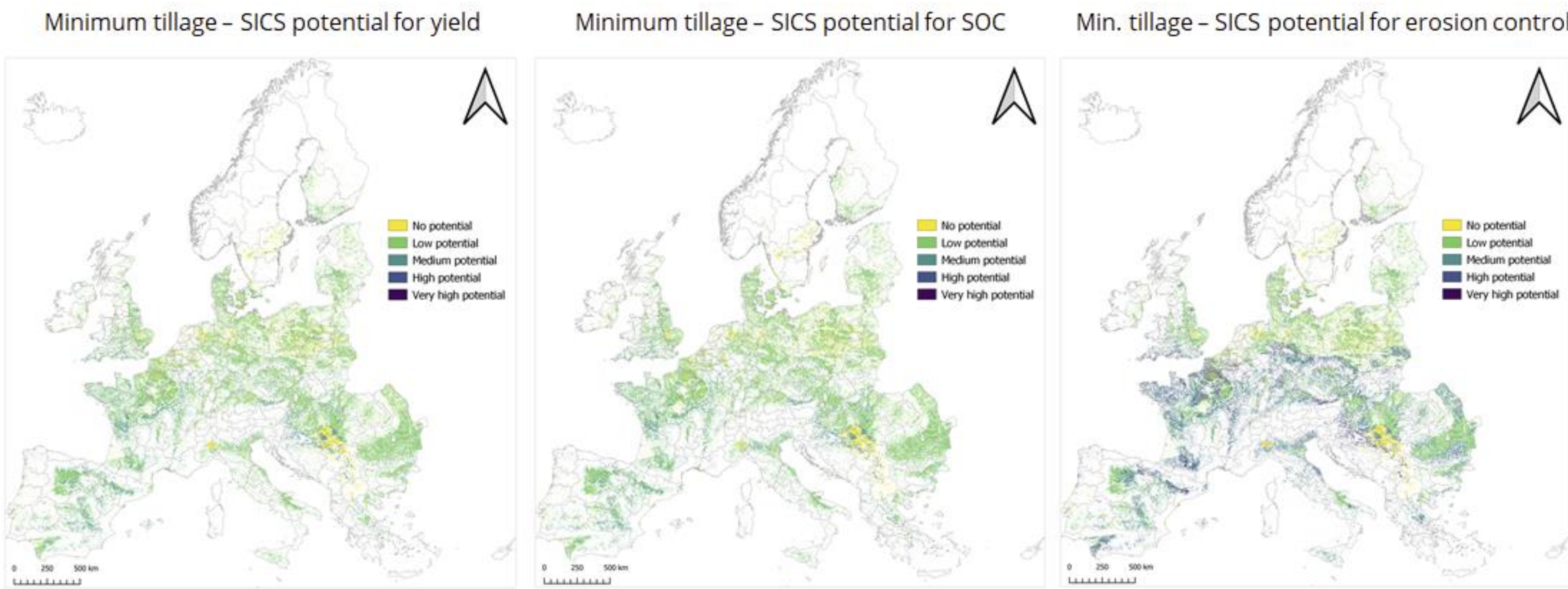


Figure 3.21: SICS potential (minimum tillage) for yield (left), SOC contents (center) and erosion control (right)

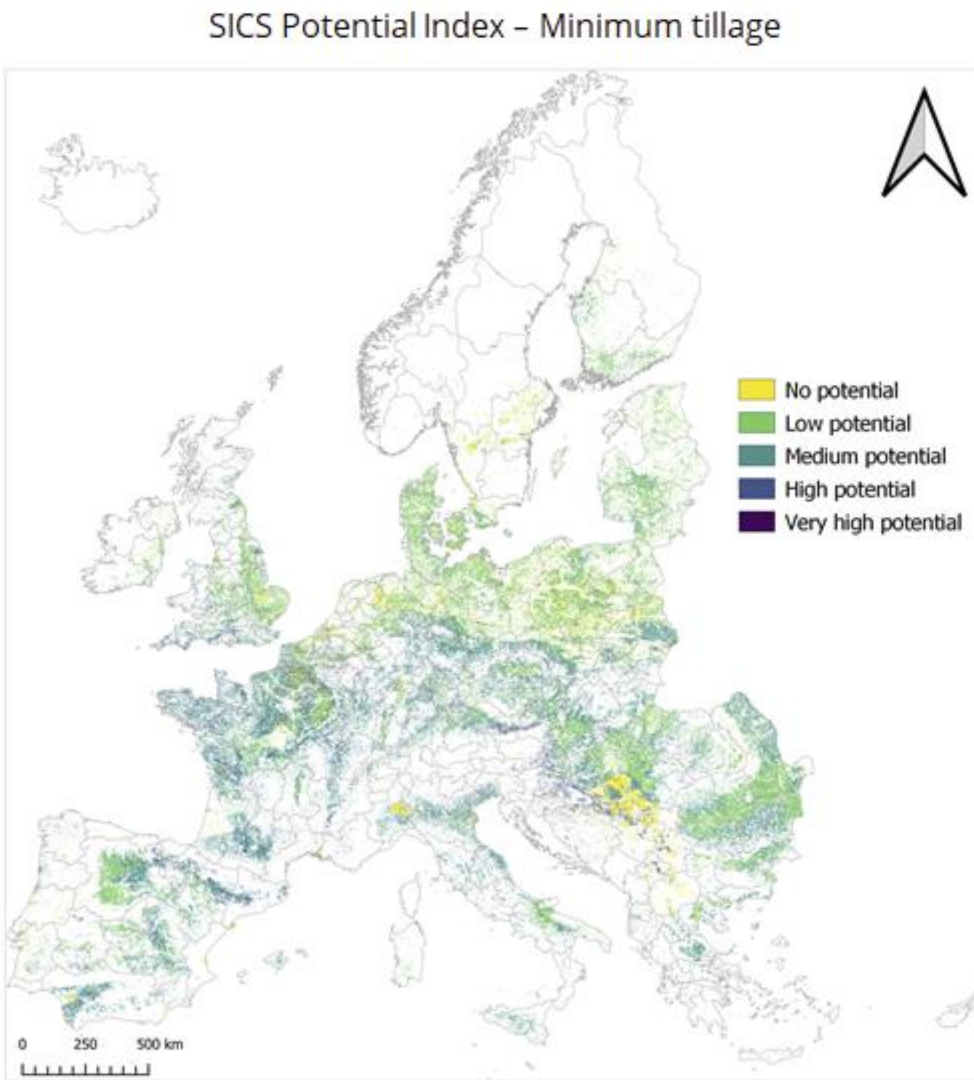


Figure 3.22: SICS Potential Index for minimum tillage

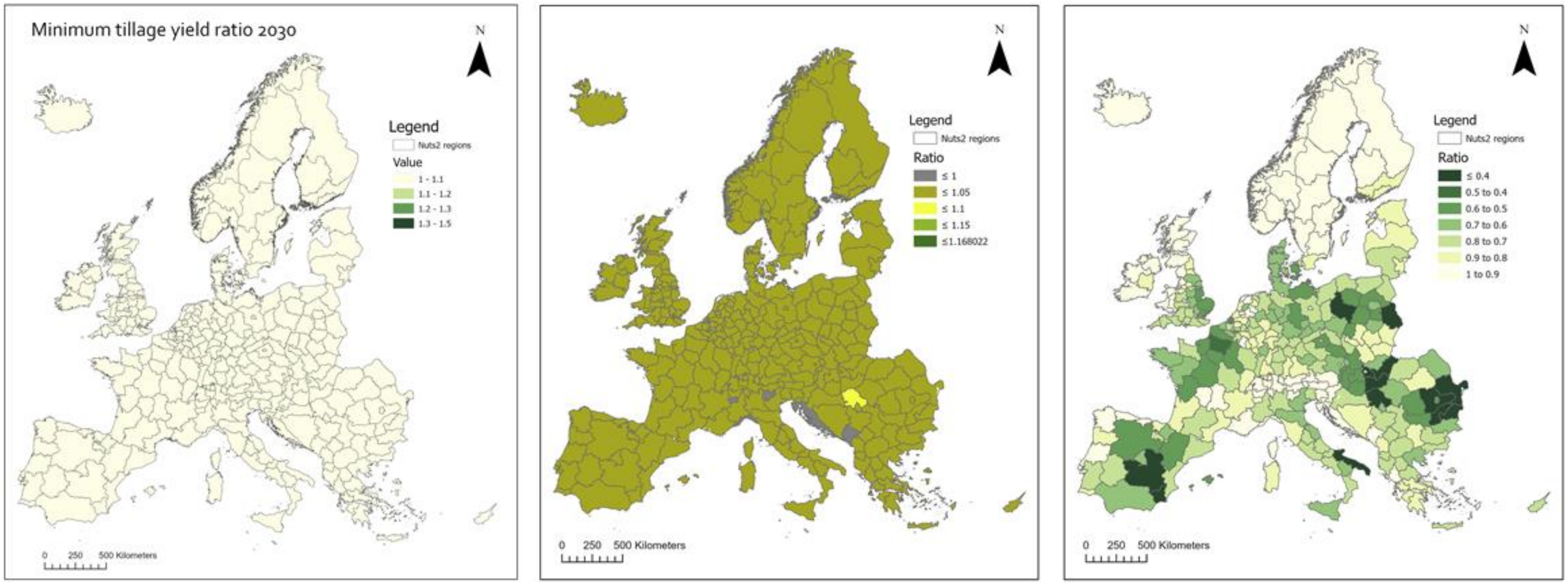


Figure 3.23: Relative impact of minimum tillage vs no measures on production (left), SOC sequestration (center) and erosion reduction (right) per NUTS-2 region

3.2.4. Compaction alleviation

Compaction alleviation includes a range of SICS that all aim to loosen compacted soil, either mechanically or through the effect of plant roots. SICS included here are: no till and cover crops (Italy), subsoil loosening (Sweden), subsoiling (Romania), using grass verges (Swiss study site), deep-rooting grass-ley cultivars, and no till (latter two both UK).

Additional application and adoption factors:

Depending on the selected SICS different adoption factors apply, so for this SICS it would be good to look at the applicability of applying various SICS, from a climate, soil, land use and socio-economic perspective. The information provided for the individual SICS in Section 3.1 supports such an assessment.

For the modelling at European scale, we have combined the applicability of these practices in the understanding that a farmer would select the practice that would be most suitable from the range of options available.

SICS Potential Index results:

The maps on the next pages indicate a high applicability of various SICS contributing to compaction alleviation across Europe, although some limitations and special consideration might be needed resulting from low rainfall or aridity (see Figure 3.24). As this SICS is actually a group of SICS all aimed to reduce compaction, areas with a medium-high compaction risk are those that are relevant for its application (see Figure 3.25). By combining both maps we see a clear reduction in area indicated by the map on the right in Figure 3.26 - showing the applicability within the relevant areas. Medium to high yield impacts are expected by reducing compaction, while SOC and erosion impacts are minor or negligible. This is reflected in SICS potential indices for yield, SOC and erosion control as well as in the overall SICS Potential Index. There are areas with a medium-high potential, but also large parts with no potential (in most of these cases, compaction is not a relevant soil threat or the SICS is not found applicable).

Regional aggregates indicate that there are specific parts of Europe where larger production benefits are expected, such as in the south, the north, England and the northern parts of Germany and Poland. Small SOC sequestration increases would be expected all over Europe, together with some minor impacts on erosion.

Sources and more information:

Information on applicability and relevance, as provided for the SICS investigated in the Italian, Romanian, Swedish, Swiss and UK study sites, is provided in Section 3.1.

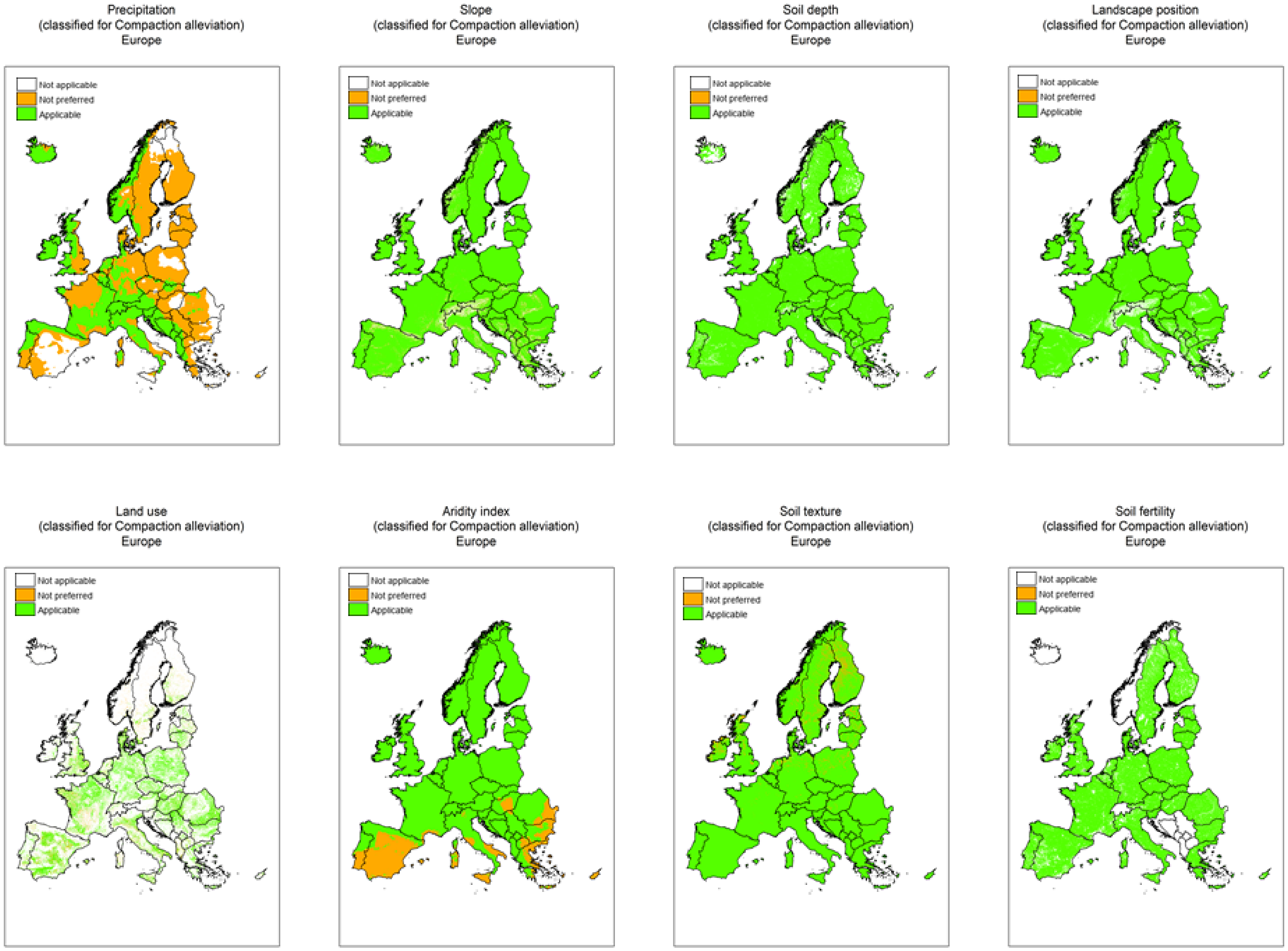


Figure 3.24: Applicability maps for compaction alleviation. Note that for countries with no data values in any of the maps, the applicability based on that factor is omitted

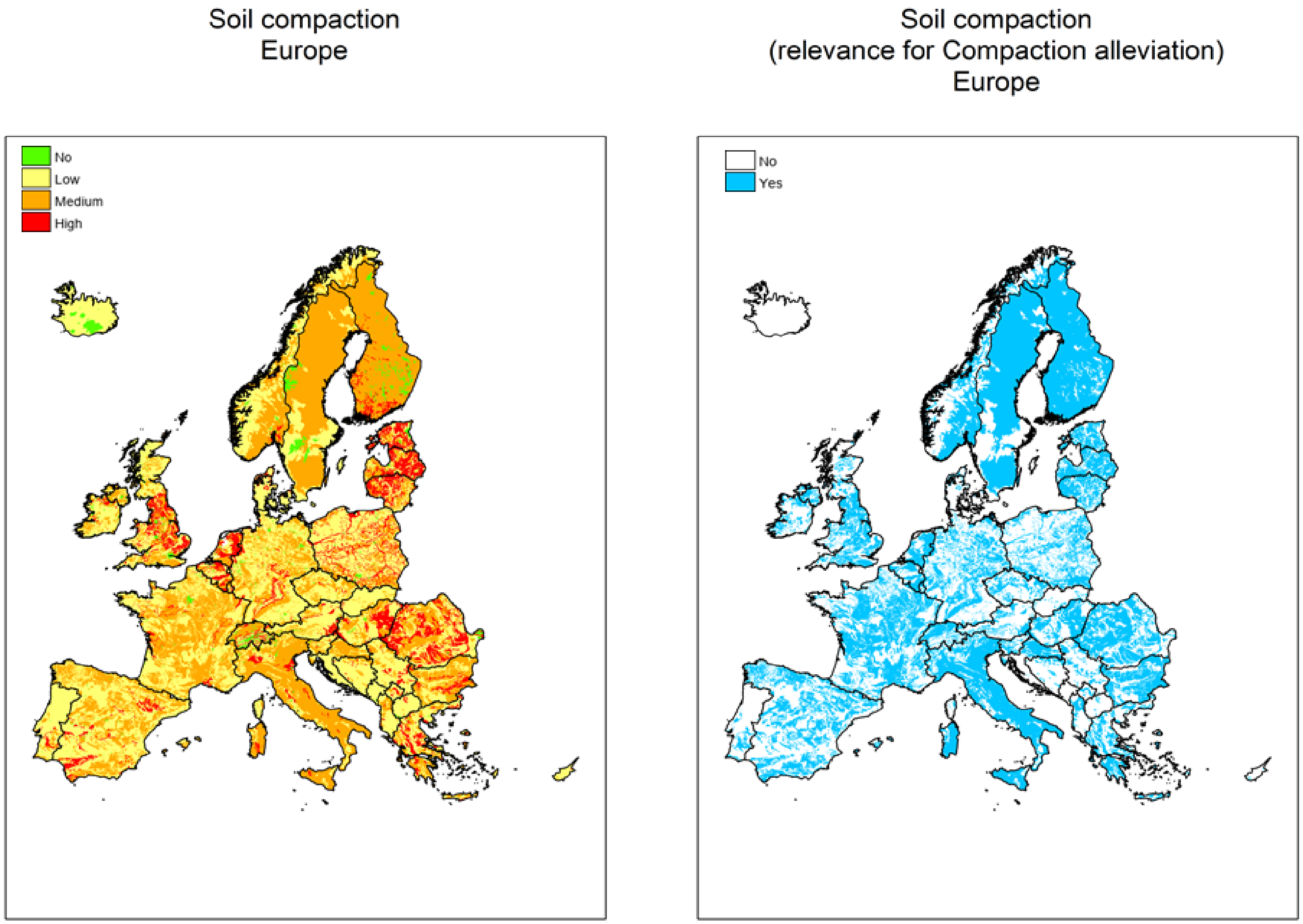


Figure 3.25: Relevance map for compaction (right) based on a compaction risk map for Europe. Medium and high categories on the compaction risk map are classified as relevant for compaction alleviation.

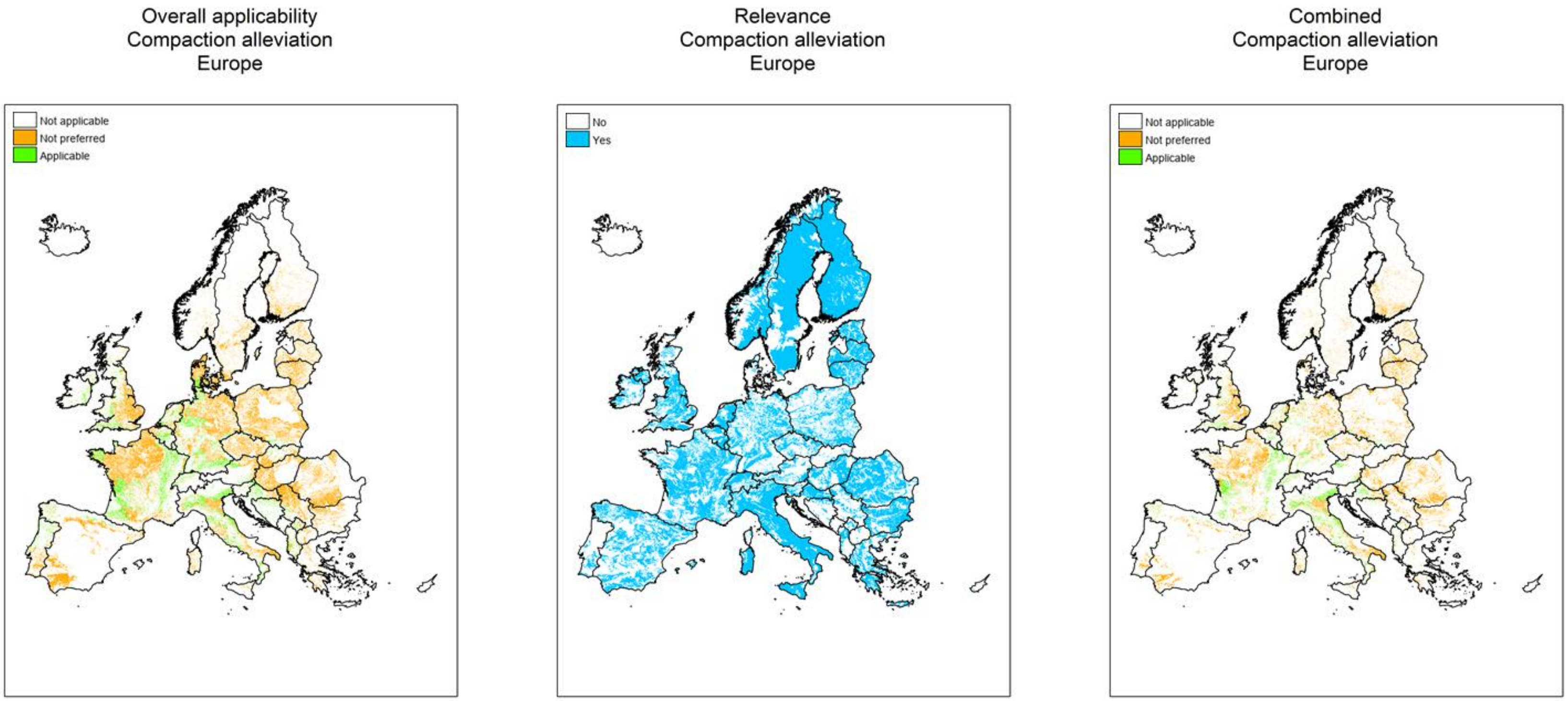


Figure 3.26: Overall (combined) applicability (left), overall (combined) relevance (center) and combined applicability / relevance (right) for compaction alleviation

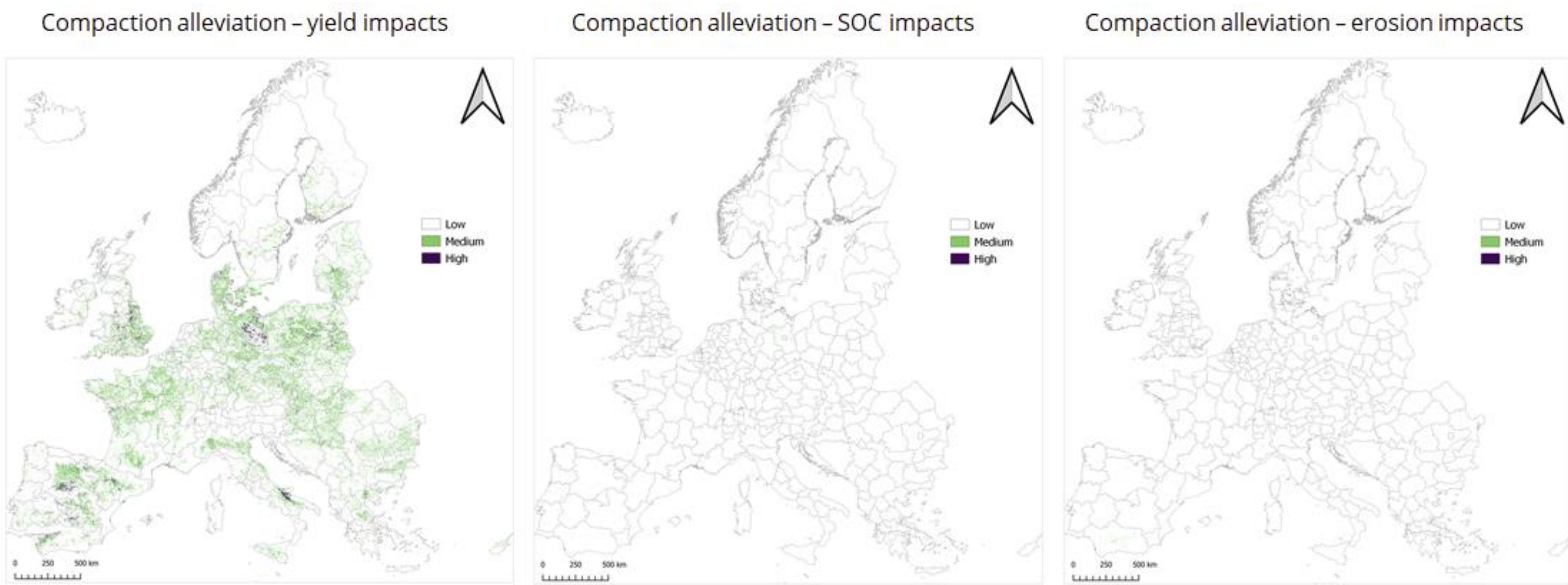


Figure 3.27: Impact of compaction alleviation vs no measures on yield (left), SOC contents (center) and erosion reduction (right)

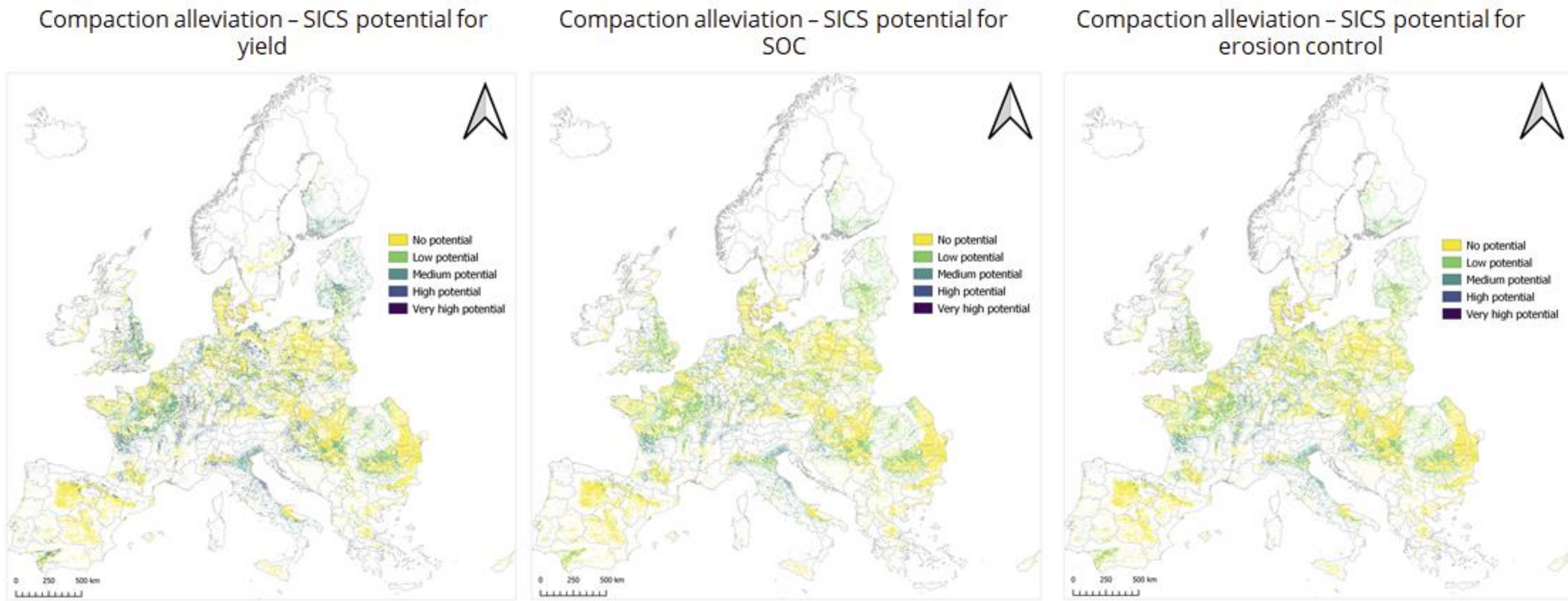


Figure 3.28: SICS potential (compaction alleviation) for yield (left), SOC contents (center) and erosion control (right)

SICS Potential Index – Compaction alleviation

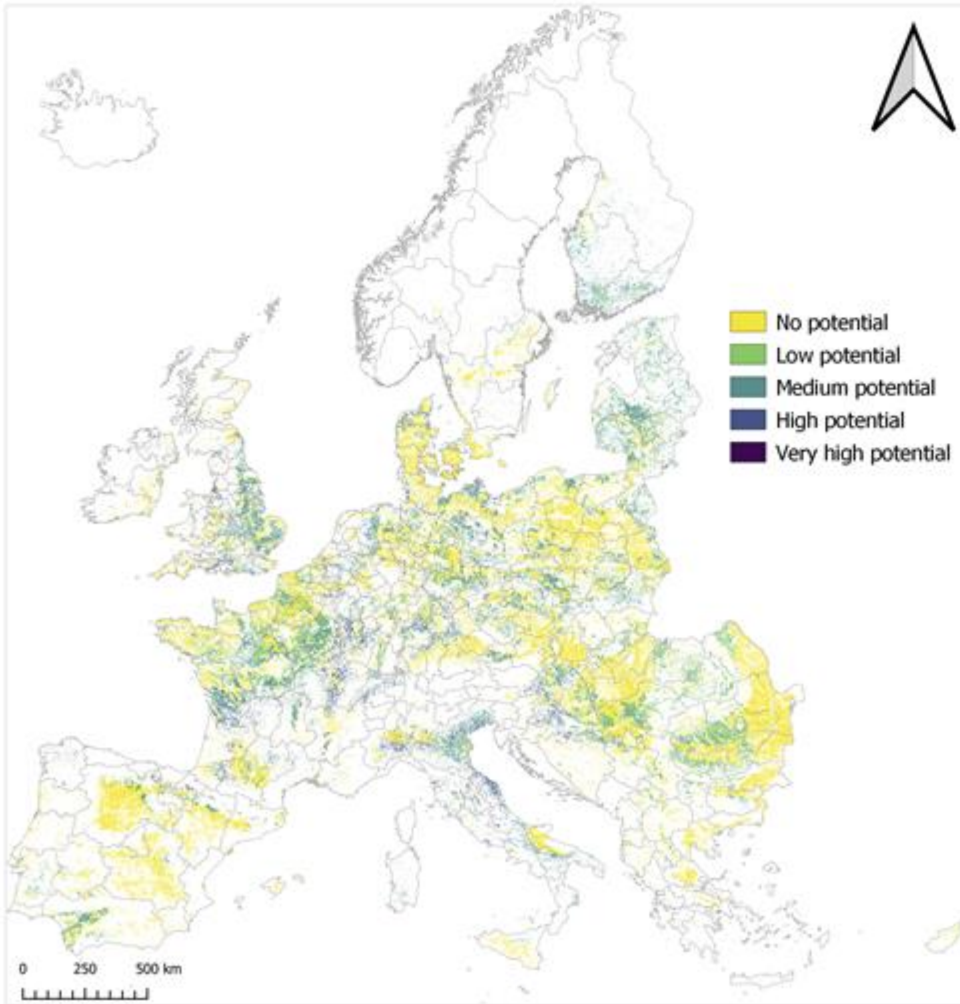


Figure 3.29: SICS Potential Index for compaction alleviation

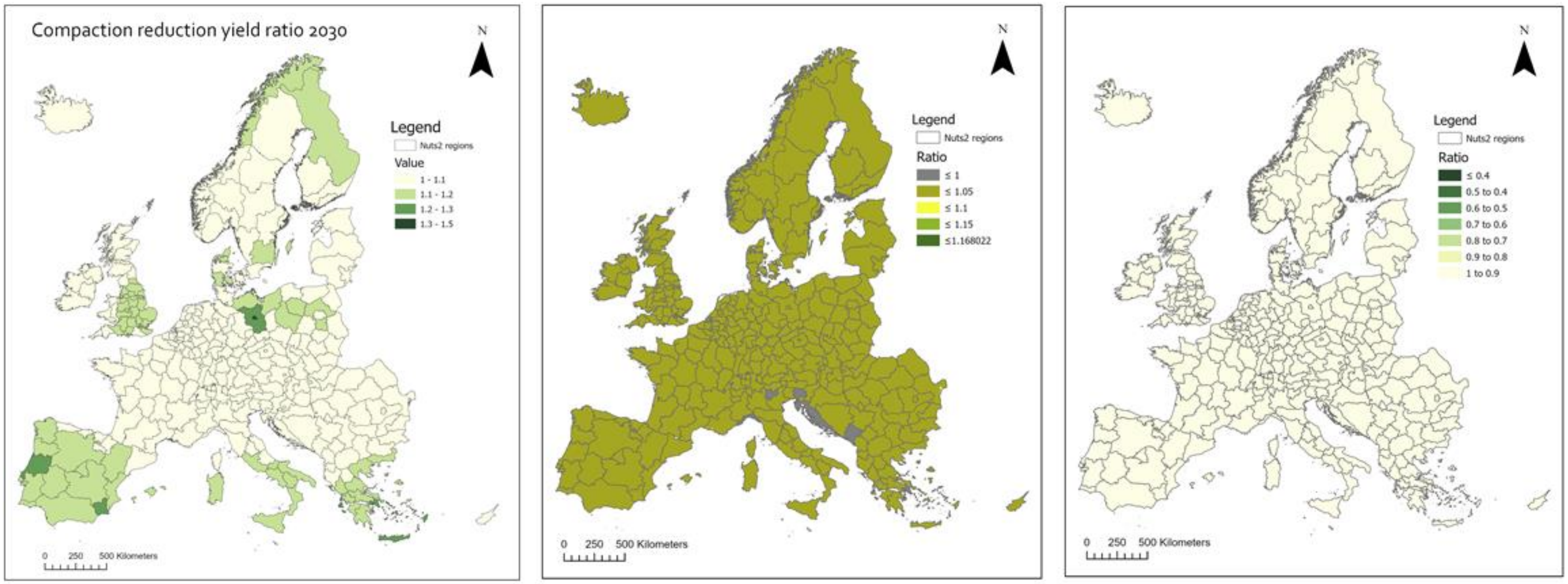


Figure 3.30: Relative impact of compaction alleviation vs no measures on production (left), SOC sequestration (center) and erosion reduction (right) per NUTS-2 region

3.3 Reflection on obtained SICS Potential Index results

Looking across the results of the four modelled SICS in Section 3.2, cover crops and mulching have a high potential throughout Europe. Mulching scores even better than cover crops as there seem to be less biophysical limitations. However, the availability of mulch is listed as a key barrier, and this is not reflected in the map results.

Cover crops and mulching score well, because they are widely applicable, relevant to mitigate soil threats or improve soil conditions in most parts of Europe and because they score well on both the sustainability and profitability indicators. Although minimum tillage still scores a medium to high SICS potential across many locations in Europe, compared to the previous SICS it scores less as the expected yield and SOC impacts are much lower. Similarly, compaction alleviation scores lower in most parts of Europe as the expected sustainability impact is less than for the other SICS.

For three of the above-mentioned SICS, emission calculations are carried out in addition to yield, SOC and erosion impacts, taking into account existing levels of SICS implementation. For compaction reduction no emission impacts were calculated as this entails a group of SICS each with special characteristics. In Table 3.3 the results of the simulation of the three soil improving practices are summarised at EU-28 level for the main environmental indicators. From the three practices, only cover crops have also an effect on the nitrogen related indicators. Cover crops can reduce the fertilizer use by 5.5% and N leaching and runoff by more than 10%. Only a small increase in N_2O emissions is simulated, due to the increase of N in crop residues.

Table 3.3: Impacts on the environmental indicators for implementation of the three soil improving practices as simulated for the EU-28 member countries.

Indicator	Baseline	Unit	Cover Crops (% change)	Reduced tillage (% change)	Mulching (% change)
N fertilizer use	11.33	Mton N	-5.5	0	0
NH_3 emission	2.75	Mton N	-1.2	0	0
N_2O emission	0.38	Mton N	0.2	0	0
N leaching and runoff	2.64	Mton N	-10.3	0	0
N soil surplus	8.80	Mton N	-7.1	0	0

In the interpretation of the results, it is important to acknowledge that the questionnaire results feeding into the applicability and relevance maps are provided by a small group of people, so local knowledge and understanding is reflected in them. Collecting feedback from a wider group of practitioners throughout Europe would strengthen the results. Furthermore, for the input and impact maps use is made of European-wide data and modelling. This comes with a certain level of abstraction that might not make conclusions applicable at regional or local level. For more detailed study we suggest repeating the approach with regional and local information. SICS can moreover also be combined. For instance, cover crops and minimum tillage are often implemented together, and this leads to additional synergies. These combinations have not been addressed in this report but are explored in D6.2.

4. Conclusions and recommendations

In this report we presented a methodology to assess the transferability of SICS investigated at study site level to other places in Europe. As a direct upscaling of results from field experiments and local stakeholder interactions isn't possible because information from one or a few small study sites wouldn't be representative, we developed an approach in which experts and stakeholders are questioned about criteria relevant for the application of SICS they are knowledgeable about (e.g. the SICS investigated in their area, although there is no requirement that it needs to be limited to these), creating regional and Europe-wide maps based on this and presenting these to the experts and stakeholders for feedback. This approach combines base maps regarding the *applicability* and *relevance* to apply SICS and combines this with the *impact* of the SICS on sustainability (SOC, water erosion) and profitability (yield) indicators to create the overall *SICS Potential Index*.

The applicability maps show that many SICS can be applied widely throughout Europe as long as the local context is taken into consideration when implementing the SICS. These conditions can be related to climate, such as a short growing season in the north of Europe, or drought, prevalent throughout Europe, although more severely in the south. Understanding what SICS to use and how to adapt it to local circumstances (e.g., the appropriate selection of type of cover crop, using a combination of techniques to mitigate potential problems) is therefore crucial and makes it possible to apply the SICS successfully even in locations where conditions might not be ideal (listed as 'not preferred' in the applicability maps).

Another important factor for transferability of SICS is their relevance. Relevance indicates where it would be useful to apply the SICS, which depends on the exact aim of the SICS. For example, a SICS might aim to increase soil quality in general, or it may aim to mitigate one particular soil threat. As, for example, different soil threats are not equally distributed over Europe, this means that the relevant area to apply a certain SICS can become larger or smaller as a function of the aim of the SICS. As many SICS are mitigating several threats and/or positively impacting several soil quality aspects (SOC increase, soil biodiversity increase), and many regions of Europe experience at least one soil threat, SICS application is relevant throughout a large part of Europe.

The approach is flexible in assessing for individual soil threats or combinations of threats, or soil quality aspects, where application in Europe would be relevant. This is demonstrated in the SoilCare Integrated Mapping Tool (IMT), where for each SICS one or more relevance factors can be selected. As applicability, relevance and impact may vary over time, it is useful to calculate the SICS Potential Index also for future years, potentially using different future conditions to better understand future uncertainties. For this reason, we have populated the SoilCare Interactive Mapping Tool (D6.3) with maps for 2018 and 2050.

The approach was valued by study site partners and scientists as it provides a visual image where the SICS could be applied and why. The combination of a questionnaire, personal communication, a spreadsheet and a slide deck with a series of maps provided a useful way to create the SICS Potential Index. Early in the process it became clear that it was difficult for those normally working at local or regional level to assess the Europe-wide maps that had been created based on the questionnaire. We therefore decided to prepare regional or national maps to enhance the understanding and support the feedback process and this proved to be very successful.

Developing and testing the SICS Potential Index throughout the project has been very useful as it helped to tailor it towards the needs of those using it. To facilitate its uptake in the future it would be useful to incorporate some of the steps in the SoilCare Interactive Mapping Tool, as is also mentioned in D6.3, as this would allow third parties to carry out their own analyses.

More specifically related to the approach, it would be good to reassess the selection of base maps as these were defined early on in the project. It might e.g., be possible to create spatially explicit information regarding some socio-economic factors, there might be additional relevance criteria that could be useful to include, or for some maps updated versions could be developed. Furthermore, more work could be spent on categorizing and aggregating the impact maps per indicator into a final impact map. And finally, regional scale field tests would be very useful to validate and/or fine-tune the settings applied to create the applicability and relevance maps. Such refinements would be expected to make the SICS potential index more versatile and more widely applicable.

In addition to fine-tuning the approach for the potential for SICS, it could be applied to other disciplines as well. Currently there is e.g., an interest in applying it to assess the potential for fuel reduction options to mitigate forest fires in Australia.

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Annex 1: Questionnaire SICS Potential Index

On the next pages a copy of the questionnaire distributed to SoilCare study site partners is included. Most of the topics listed under climate and soil have been used to prepare the applicability maps together with the selection of crops the SICS could be applied to listed under 'land use' in the socio-economic and land use part of the questionnaire. Relevance maps were based on questions 4 and 5. Not all information in the questionnaire is useful for a spatially-explicit representation. Non-spatial information was used to write the accompanying text for each of the SICS in Section 3.1.

1. Case study region

   …

2. Name of person and group/organisation filling in questionnaire

   …

3. Name and brief description of the SICS

   …

4. What is the aim of applying the SICS? Are certain soil parameters targeted specifically? If the aim is solely to prevent or mitigate a soil threat or restore the soil due to a threat, please go to question 5.

   ….

5. What soil threats does the SICS impact on? (More options possible), If soil threats are not relevant, please tick this box ☐.

Major impact	**Minor impact**	**Soil threat**
☐	☐	Erosion by wind
☐	☐	Erosion by water
☐	☐	Decline in organic matter in peat soils
☐	☐	Decline in organic matter in mineral soils
☐	☐	Soil compaction
☐	☐	Soil contamination, diffuse source
☐	☐	Soil contamination, point source
☐	☐	Soil salinization
☐	☐	Desertification
☐	☐	Landslides
☐	☐	Flooding
☐	☐	Decline in soil biodiversity

Comments:

6. In case you have provided an answer under 5, is the SICS used for prevention, mitigation and/or restoration? (More options possible)

Mostly	**To some extent**	**Threat severity**
☐	☐	Prevention
☐	☐	Mitigation
☐	☐	Restoration

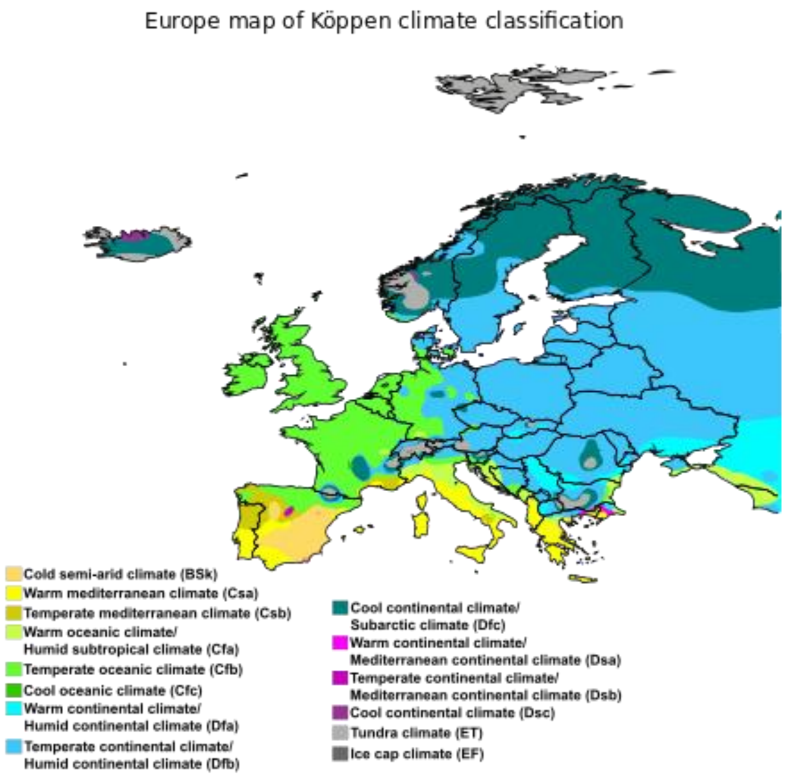
Comments:

Climate

7. During what period of the year is the SICS applied? Please place a cross (X) under the relevant month.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

8. In what climate regime can the SICS be applied? (More options possible). If the climate regime is not relevant, please tick this box ☐.



Yes	**Not preferred**	**No**	**Climate regime**
☐	☐	☐	Cold semi-arid
☐	☐	☐	Warm mediterranean
☐	☐	☐	Temperate mediterranean
☐	☐	☐	Warm oceanic / Humid subtropical
☐	☐	☐	Temperate oceanic
☐	☐	☐	Cool oceanic
☐	☐	☐	Warm continental / Humid continental
☐	☐	☐	Temperate continental
☐	☐	☐	Cool continental / Subarctic
☐	☐	☐	Warm continental / Mediterranean continental
☐	☐	☐	Temperate continental / Mediterranean continental
☐	☐	☐	Cool continental
☐	☐	☐	Tundra
☐	☐	☐	Ice cap

Comments:

9. In what agro-climate regime can the SICS be applied (expressed as length of growing period)? (More options possible). If the agro-climate regime is not relevant, please tick this box ☐.

Yes	Not preferred	No	Agro-climate regime
☐	☐	☐	>270 days
☐	☐	☐	180-269 days
☐	☐	☐	75-179
☐	☐	☐	0-74 days

Comments:

10. Under what average annual rainfall (mm) conditions is the SICS applicable? (More options possible). If average annual rainfall conditions are not relevant, please tick this box ☐.

Yes	Not preferred	No	Average annual rainfall(mm) range
☐	☐	☐	< 250
☐	☐	☐	250-500
☐	☐	☐	500-750
☐	☐	☐	750-1000
☐	☐	☐	1000-1500
☐	☐	☐	1500-2000
☐	☐	☐	2000-3000
☐	☐	☐	3000-4000
☐	☐	☐	>4000

Comments:

11. Under what average annual PET(mm) range is the SICS applicable? (More options possible. If the average annual PET range is not relevant, please tick this box ☐.

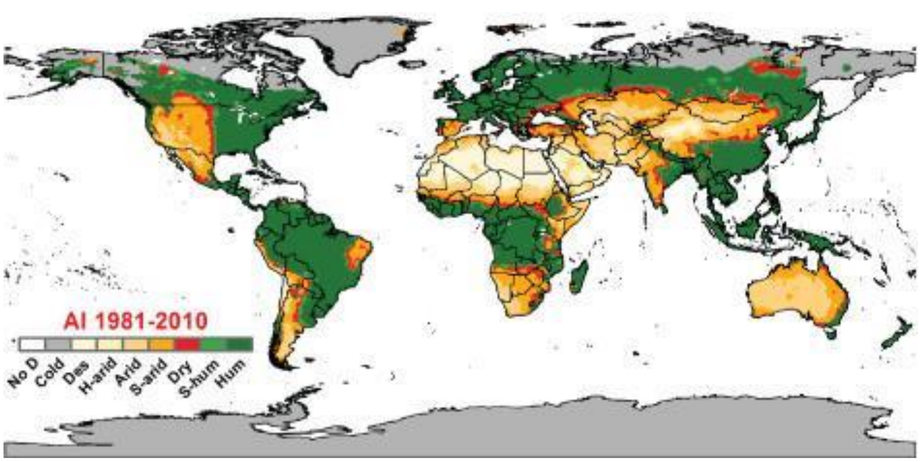
Yes	Not preferred	No	Average annual PET(mm) range
☐	☐	☐	< 250
☐	☐	☐	250-500
☐	☐	☐	500-750
☐	☐	☐	750-1000
☐	☐	☐	1000-1500
☐	☐	☐	1500-2000
☐	☐	☐	2000-3000
☐	☐	☐	3000-4000
☐	☐	☐	>4000

Comments:

12. Under what aridity index is the SICS applicable? (More options possible). If the aridity index is not relevant, please tick this box ☐.

Yes	Not preferred	No	Average annual PET(mm) range
☐	☐	☐	< 0.05 (hyperarid)
☐	☐	☐	0.05 – 0.2 (arid)
☐	☐	☐	0.2 – 0.5 (semi-arid)
☐	☐	☐	0.5 – 0.65 (dry sub-humid)
☐	☐	☐	> 0.65

Comments:



13. Are there climate limitations related to a specific season or month? Consider e.g. temperature, precipitation, precipitation / PET and consider tolerance and sensitivity to extremes.

Examples:

A. *A certain permanent cover crop could require average monthly temperatures in critical winter months (December, January) to be above 7 ˚C, and in a critical summer month (August) to be below 30 ˚C.*

B. *A certain SICS could require average annual rainfall to be greater than 500mm, of which at least 50 mm is on average required in spring months and no more than 200 mm in total in autumn (N. Hemisphere).*

C. *A certain SICS could require rain > 50% of the evaporation for a certain amount of time, e.g. number of months*

It is also possible to evaluate simple expressions based on multiple data layers, e.g. a quotient of precipitation and potential evapotranspiration to evaluate whether the growing season extends in summer.

….

14. Are there any other climate aspects relevant for the application of the SICS? If so, please elaborate.

….

15. Please rank the most important climate aspects by entering the aspect behind the rank. If less than five aspects are relevant, please only fill in the relevant aspects.

1.	
2.	
3.	
4.	
5.	

Comments:

Soil

16. What are relevant slopes for application of the SICS? (More options possible). If slope is not relevant for application of your SICS, please tick this box ☐.

Yes	**Not preferred**	**No**	**Slope**
☐	☐	☐	Flat (0-2 %)
☐	☐	☐	Gentle (2-5 %)
☐	☐	☐	Moderate (5-8 %)
☐	☐	☐	Rolling (8-16 %)
☐	☐	☐	Hilly (16-30%)
☐	☐	☐	Steep (30-60%)
☐	☐	☐	Very steep (>60 %)

Comments:

17. What are relevant average soil depths for application of the SICS? (More options possible). If soil depth is not relevant for the application of your SICS, please tick this box ☐.

Yes	**Not preferred**	**No**	**Soil depth**
☐	☐	☐	Very shallow (0-20 cm)
☐	☐	☐	Shallow (20-50 cm)
☐	☐	☐	Moderately deep (50-80 cm)
☐	☐	☐	Deep (80-120 cm)
☐	☐	☐	Very deep (> 120 cm)
☐	☐	☐	Soil depth not relevant

Comments:

18. In what landforms can the SICS be applied? (More options possible). If the landform is not relevant, please tick this box ☐.

Yes	Not preferred	No	Landform
☐	☐	☐	Plateau / plains
☐	☐	☐	Ridges
☐	☐	☐	Mountain slopes
☐	☐	☐	Hill slopes
☐	☐	☐	Footslopes
☐	☐	☐	Valley floors

Comments:

19. To soils with what kind of soil fertility is itrelevant to apply the SICS? (More options possible). If soil fertility is not relevant, please tick this box ☐.

Yes	Not preferred	No	Soil fertility
☐	☐	☐	Very high
☐	☐	☐	High
☐	☐	☐	Medium
☐	☐	☐	Low
☐	☐	☐	Very low

Comments:

20. What types of soil texture are relevant to apply the SICS to? (More options possible). If soil texture is not relevant for application of your SICS, please tick this box ☐.

Yes	Not preferred	No	Soil texture
☐	☐	☐	Coarse / light (sandy)
☐	☐	☐	Medium (loam)
☐	☐	☐	Fine / heavy (clay)
☐	☐	☐	Organic

Comments:

21. Are there specific soil characteristics relevant for the application of the SICS? And if so are there ranges of these characteristics where you would or would not apply the SICS? Why?

    ….

22. Are there any other soil aspects relevant for the application of the SICS (e.g. pests, soil pathogens, natural drainage conditions)? If so, please elaborate.

23. Can you rank the soil aspects in order of importance for their importance in adoption of the SICS? Please enter a number from 1 to 5 in the cell before the aspect (column 'Rank'). If less than 5 aspects are relevant, only rank those aspects which are relevant. In case two aspects are equally relevant, please give them the same rank.

Rank	**Soil aspect**
	Slope
	Soil depth
	Land form
	Soil fertility
	Soil texture
	Other, please specify…

Socio-economic and land use

24. What types of land use are relevant to apply the technique to? (More options possible). If your SICS is a rotation of crops, please indicate this rotation in the comments if you haven't provided information on the rotation earlier in the questionnaire. If land use types are not relevant in the application of the SICS, please tick this box ☐.

Yes	**Not preferred**	**No**	**Land use type**
☐	☐	☐	Cereals, irrigated
☐	☐	☐	Cereals, non-irrigated
☐	☐	☐	Root crops, irrigated
☐	☐	☐	Root crops, non-irrigated
☐	☐	☐	Vegetables, irrigated,
☐	☐	☐	Vegetables, non-irrigated
☐	☐	☐	Other annual crops, irrigated, please specify…
☐	☐	☐	Other annual crops, non-irrigated, please specify…
☐	☐	☐	Permanent crops, irrigated, please specify…
☐	☐	☐	Permanent crops, non-irrigated, please specify…
☐	☐	☐	Greenhouse crops, please specify…
☐	☐	☐	Grazing land
☐	☐	☐	Forests / woodlands
☐	☐	☐	Mixed
☐	☐	☐	Other, please specify…

Comments, e.g. applicability to specific crop types:

25. Does applying the SICS generally require purchasing new equipment?

    Yes / no (please remove the incorrect answer). If yes, what type of equipment?
    ….

26. Are there specific conditions that would make application of the SICS more or less expensive (investment as well as recurrent costs)?

    ….

27. What is the financial viability of the SICS, also in comparison to more conventional techniques? (More options possible).

Yes	Maybe	No	Financial viability
☐	☐	☐	Financial incentives required to make the technique profitable
☐	☐	☐	Benefits outweigh costs, but only after a few years
☐	☐	☐	Same cost-benefit ratio as the conventional practice
☐	☐	☐	Higher costs than the conventional practice
☐	☐	☐	Lower costs than the conventional practice
☐	☐	☐	Higher benefits than the conventional practice
☐	☐	☐	Lower benefits than the conventional practice
☐	☐	☐	Other, …

Comments:

28. When you apply/install the SICS, how long does it take before the desired effect can be observed?

….

29. When you stop with the SICS, how long does it take before the positive impacts are no longer noticeable?

….

30. What is the level of expertise required to apply the SICS?

☐ Low
☐ Medium
☐ High

Comments:

31. How critical is correct application of the SICS in order for it to be effective?

☐ Low
☐ Medium
☐ High

Comments:

32. To what farm size / area per household (ha) is the SICS applicable? (More options possible). If farm size is not relevant for application of the technique, please tick this box ☐.

Yes	**Not preferred**	**No**	**Farm size**
☐	☐	☐	< 0.5
☐	☐	☐	0.5-1
☐	☐	☐	1-2
☐	☐	☐	2-5
☐	☐	☐	5-15
☐	☐	☐	15-50
☐	☐	☐	50-100
☐	☐	☐	100-500
☐	☐	☐	500-1,000
☐	☐	☐	1,000-10,000
☐	☐	☐	>10,000

Comments:

33. To what plot size is the SICS applicable? (More options possible). If plot size is not relevant for application of the technique, please tick this box ☐.

Yes	Not preferred	No	Farm size
☐	☐	☐	< 0.5
☐	☐	☐	0.5-1
☐	☐	☐	1-2
☐	☐	☐	2-5
☐	☐	☐	5-15
☐	☐	☐	15-50
☐	☐	☐	50-100
☐	☐	☐	100-500
☐	☐	☐	500-1,000
☐	☐	☐	1,000-10,000
☐	☐	☐	>10,000

Comments:

34. To what farm type is the SICS applicable? (More options possible). If the farm type is not relevant for the application of the technique, please tick this box ☐.

Yes	Not preferred	No	Farm type
☐	☐	☐	Part-time
☐	☐	☐	Small: subsistence (SF) / semi-subsistence (SSF)
☐	☐	☐	Small commercial
☐	☐	☐	Large commercial
☐	☐	☐	Conventional
☐	☐	☐	Organic
☐	☐	☐	Other, please specify

Comments:

35. Are there any other social, cultural, or economic aspects relevant for the application of the SICS? If so, please elaborate.

….

36. Can you rank the socio-economic aspects below in order of importance for adoption of the SICS? Please enter a number from 1 to X in the cell before the aspect (column 'Rank'), with X being the total number of relevant aspects. Only rank those aspects which are relevant. In case two aspects are equally relevant, please give them the same rank.

Rank	Socio-economic aspect
	Financial capability to implement the technique without support
	Availability of subsidies
	Willingness of farmer
	Political willingness
	Awareness of the technique
	Understanding of the technique
	Proven effectiveness of the technique
	Application of the technique by peers
	Education level of the farmer (or other person implementing the technique)
	Age of the farmer (or other person implementing the technique)
	Farm size
	Farm type
	Sole dependence of household income from farming
	Having a successor
	Part of the cultural heritage
	Availability of large programmes and related funding
	Part of legislative requirements
	Other, please specify…

37. Any additional comments or considerations regarding the SICS and its applicability?

…

38. Under what broader group of techniques would your technique fall (e.g. minimal straw mulching could fall under mulching and grassed waterways under vegetative run-off reduction)?

…