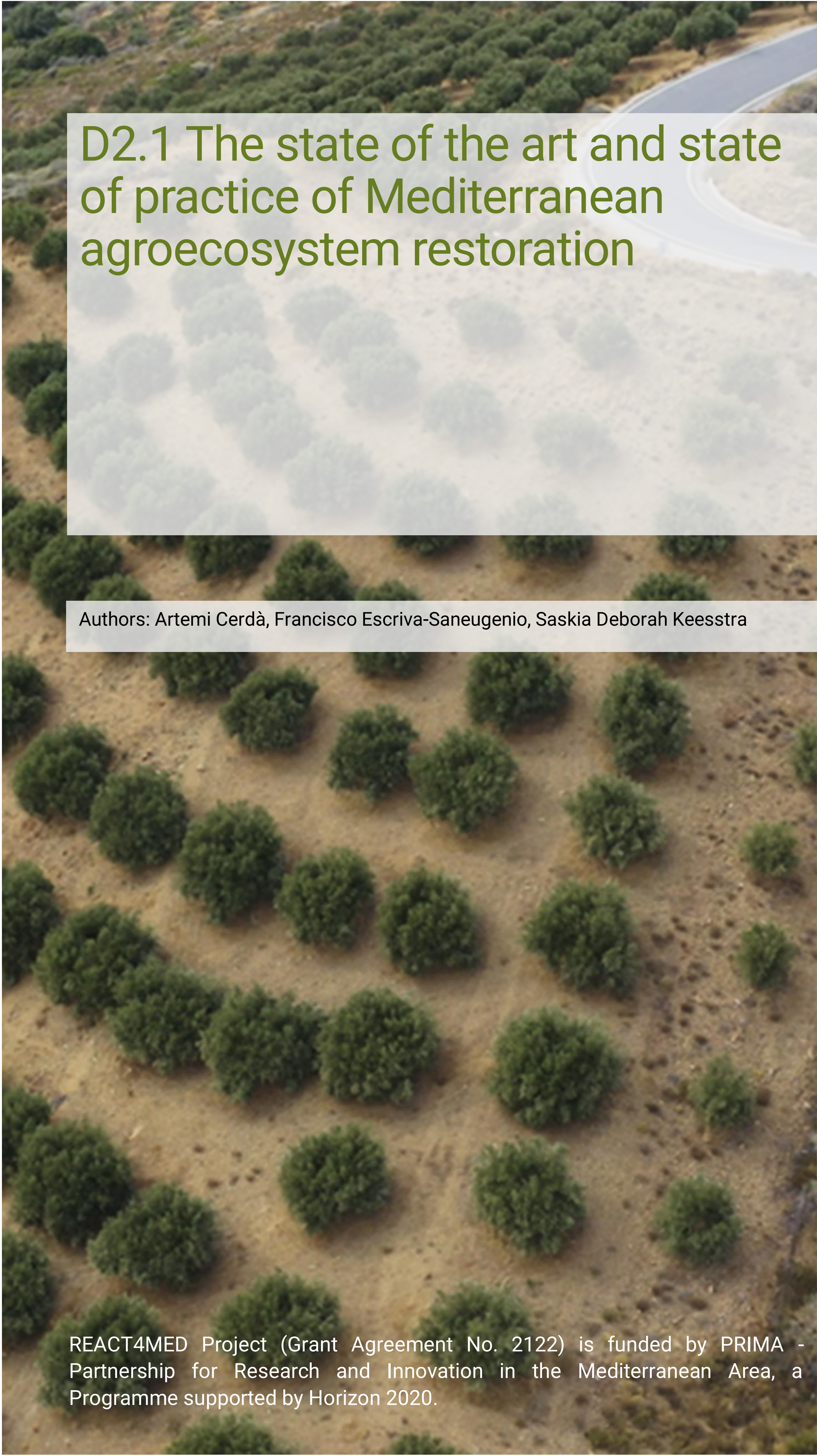

D2.1 The state of the art and state of practice of Mediterranean agroecosystem restoration

Authors: Artemi Cerdà, Francisco Escriva-Saneugenio, Saskia Deborah Keesstra

REACT4MED Project (Grant Agreement No. 2122) is funded by PRIMA - Partnership for Research and Innovation in the Mediterranean Area, a Programme supported by Horizon 2020.

This page is intentionally left blank

Technical References		
Project Acronym	REACT4MED	
Project title	Inclusive Outscaling of Agro-ecosystem REstoration ACTions for the MEDiterranean	
Project coordinator	HMU	
Project Duration	36 months	
Deliverable No.	D2.1	
Deliverable title	The state of the art and state of practice of Mediterranean agroecosystem restoration	
Lead partner	UVEG	
Contributing partners		
Author(s)	Artemi Cerdà, Francisco Escriva-Saneugenio, Saskia Deborah Keesstra	
Editor(s)		
Type	Text	
Format	MS-Word	
Language	EN-GB	
Creation date	2023.02.28	
Version number	1.0	
Version date		
Last modified by		
Due date	2023.02.28	
Actual delivery date		
Rights	Copyright © 2023, REACT4MED Consortium	
Dissemination level		CO (confidential, only for members of the consortium)
	X	PU (public)
		PP (restricted to other programme participants)
		RE (restricted to a group specified by the consortium)
	When restricted, access granted to:	
Nature	X	R (report)
		P (prototype)
		D (demonstrator)
		O (other)

Revision history			
Version	Date	Modified by	Comments
1.0	2023.02.28	ID_ UVEG	

Table of Contents

Executive Summary iv
Abstract 1
1 Introduction 1
2 Methodology 5
3 A Pan-European approach based on the EU projects, and scientific literature review with comments to the Middle East and North African region 6
4 Soils as a key actor in climate change mitigation. The role of organic matter and soil erosion 14
5 Soil degradation. What is accepted? Looking forward solutions for agricultural land 16
5.1 Project objectives 18
5.2 Organic amendments 18
5.3 Covers 19
5.4 Agroforestry and land abandonment 22
5.5 No disturbance and no-tillage 23
5.6 An overview 25
6 Barriers to the new management 26
7 Conclusions 26
Acknowledgements 27
Literature 27

Executive Summary

TO BE FILLED IN WHEN FINAL

Abstract

Agriculture is known to commonly cause soil degradation. In the Mediterranean, agriculture is ten millennia old, and the soils have been degraded due to mining, fire, tillage, and overgrazing. In the last century, the use of pesticides and machinery, and the intensification of production (agribusiness and monoculture) also created new threats to soil health. Consequently, agriculture it is been seen as a driver of soil degradation. This report assesses the current State-of-the-Art of soil degradation in the Mediterranean and reviews the practices in Mediterranean Ecosystems and sheds light on the restoration programs. We review and analyze available literature from well-documented past and ongoing restoration projects and initiatives to identify good practices and approaches. The literature from key EU research projects and scientific papers inform that soils are affected by different threats (erosion, compaction, pollution…) that induce the loss of soil services and that the Mediterranean is the area more affected. The scientific research informs that there are strategies to preserve the soil and restore the soil functions and soil services in the Mediterranean belt such as the use of catch crops, cover crops, mulching, and organic fertilization. Restoring the agricultural soils can be also a solution to fight against global warming as soils can act as sinks of carbon. The main constraints to applying sustainable management are social, economic, and perception from farmers. The policies developed by the EU are very positive to restore soil services, but there are some barriers to expanding sustainable management to the whole community of farmers. There is a need to develop strategies to outscale the management applied and tested to the landscape and overall use by farmers. There is a lack of scientific research in the long term to determine the impact of the new management. It is necessary to develop lighthouse farms and living labs to test the new strategies that will substitute herbicide (traditional No-Tillage) and tillage management in a more sustainable management of the land with catch crops, cover crops, and mulches.

1 Introduction

Twenty-two percent (3 billion ha) of the continents on Earth are cultivable, while 66% out of them (2 billion ha) has been degraded (UNDP, 2019) while ninety-five percent of what humans consume comes from the land, either directly or indirectly (FAO, 2015). Over the last decades, land degradation has affected 20% of the total land area covered by vegetation over the last two decades, affecting more than 1.5 billion people worldwide (UNCCD, 2017). Between 1985 and 2005, the area of agricultural land in severely degraded landscapes increased by 2.41 percent (Foley et al., 2011), and globally approximately 10 million ha of land were lost at the beginning of this century (IAEA, 2018; 2020). Given the scarcity of agricultural land and the anticipated rise in demand for agricultural commodities by 2050 (Foley, 2011), the fate of life on Earth depend on the health and diversity of the land and soil ecosystem.

Soil is a key component of the Earth's System and its degradation results in a lack of sustainability and endangers human societies (Keesstra et al., 2016). Soil degradation is a global problem endangering sustainable development. The loss of the soil is the complete degradation of the soil system as without soil there will be no turnover of nutrients, no plants, and no food for humans (Keesstra et al., 2018). Within the threats to the soil system, soil erosion is a major environmental problem in the world, it has been considered the worst type of land degradation (FAO, 2000).

Soil degradation is a global problem that will result in the failure of sustainable development programs if not solved (Jie et al., 2002). However, there are other threats to the sustainable use of soils (Stolten et al., 2016). Soil biodiversity is threatened by the current soil management (Gardi et al., 2013), and soil salinity reduces soil health and production (Daliakopoulos et al., 2016a; 2016b). Compaction, pollution, sealing, loss of soil structure, and organic matter decay, are some examples of soil degradation in Europe (Tóth et al., 2016) and therefore the EU member states develop policy instruments to protect the soil (Ronchi et al., 2019).Capitalize on the scientific and practical knowledge established by past and on-going restoration projects, and critically review sustainable land management practices and approaches (WP2).

Figure 1. Agricultural soils are the primary source of food. Dembecha, West Gojam, Ethiopia. It is compulsory to preserve soils and landscapes to maintain their services for future generations

Soil erosion has been seen as the main cause of soil degradation, but also the consequences of soil degradation that induced compacted soils, lack of organic matter and bare soils are important (Dregne, 1987). Soil erosion is a natural process in which the topsoil is carried off the ground by water or wind and moved to another place. The interaction between land use, topography, rainfall intensity, and soil type determined the soil erosion rates. Although soil erosion occurs naturally it is frequently worsened by human activities through agricultural intensification, deforestation, over-cultivation, and overgrazing (Narayan et al., 2018). Land deterioration decreases agricultural production due to the loss of nutrients on the surface of the soil, topsoil erosion, and lower water quality which are all results of soil erosion (Shinde et al.; 2010; Wolka et al., 2018). This in turn directly influences the environment and economy, as well as siltation of the watersheds. However, soil erosion, either by wind or water, is not a unique threat to the soil system. Other soil threats are the decline of organic matter in mineral and peat soils, soil compaction, soil sealing, soil contamination, and soil salinization (Daliakopoulos et al., 2019). The impact of soil degradation induces land desertification but also flooding and landslides. All the above-mentioned soil threats contribute to the reduction of soil biodiversity and affect the ecosystem services and the main soil functions. The degradation of the soil will result in a more unstable ecosystem and a threat to healthy food production. The main drivers of soil degradation are climate change and inappropriate land use and poor management (Karlen and Rice, 2015). The societal, economic, and policy impact on soil degradation determines land use and land management (Wynants et al., 2019).

Figure 2. View of degraded land as a consequence of agriculture mismanagement that results in high erosion rates (gullying) in Iran (Isfahan) and a group of REACT4MED scientists visiting an experimental farm in Israel where No-Tillage is applied. Healthy soils is the best strategy to recover agriculture sustainability

Soil degradation in Europe is accepted to be a threat today. Regional studies highlighted the importance of soil degradation in Europe (Marchetti et al., 2012; Colantoni et al., 2015; Šarapatka and Bednář, 2015; Daliakopoulos et al., 2016). The Common Agricultural Policy of the European Union promotes farming practices that support soil conservation. Still, there is a need for soil monitoring networks that must be improved with the Living Labs and Lighthouse experimental farms. Europe is now in the reconciling the way we use the soils and how we design a sustainable use of the resources (EJP SOIL). A major policy shift is ongoing with the implementation of the EU Mission 'A soil deal for Europe'. This Mission has as its overarching goal to establish 100 living labs and lighthouses by 2030 that should lead the way to healthy soils across Europe.

The Mediterranean region has been considered the most susceptible region in Europe to soil degradation and desertification (Ferreira et al., 2022). The reason why the Mediterranean is threatened by the soil degradation processes is due to a set of regional conditions: i) the continuous use of the land since agriculture was developed ten millennia ago, ii) the climatic conditions with yearly drought (summer), iii) the intense rainfall events, and iv) the rugged terrain due to the alpine movement. The combined conditions contribute to high sediment yield and enhance the detachment and transport of soil particles from the slopes and contribute to creating alluvial plains and deltas. The green revolution during the second half of the 20th century worsened the conditions with the use of pesticides (reduction in biodiversity), herbicides (reduction in vegetation and increase in soil erosion and organic matter loss), monoculture, and commercial agriculture (market-oriented). In the last decades a new threat appeared on the horizon: climate change, which intensified the degradation of the soils due to loss of vegetation cover, droughts, and higher intensity rainfall events. Lastly, there is also a social and economic impact on soil degradation. The low income of farmers finally results in land abandonment and the aging of the rural population.

Figure 3. Soil restoration field experiments in Romania (Sibiu) and Iceland were visited by the participants of the RECARE project where the restoration was analized under different climatic conditions and land uses

The objective of this report is to review and analyze available literature from well-documented past and ongoing restoration projects and initiatives to identify good practices and approaches. The literature review (a State-of-the-Art) will bring information about the biophysical and socio-economic impacts, associated benefits and trade-offs, adoption facilitators and enhancers, and lessons learned, as well as from successes and failures. This will consolidate existing knowledge and will inform about the success of the practices introduced. We give special attention to the economic instruments, mechanisms, and innovations that facilitate public and private investment in Sustainable Land and Water Management that will guide future policies. Our State-of-the-Art is based on the key research project reports from past and running projects and programs in Europe (CASCADE, RECARE, SoilCare, LEDDRA, EJP SOIL, and CIRCASA); and published scientific papers that show examples of practices and their impact on the soil system. Our review has been inspired by the expertise of the REACT4MED PRIMA Project and beyond to bring an overview of the whole Mediterranean. The review will focus on sustainable management as an alternative to currently often used chemically based management, and our findings contribute to a list of baseline assessment indicators at various spatial scales.

2 Methodology

This report is based on the review of the reports of CASCADE, RECARE, SoilCare, LEDDRA, EJP SOIL, and CIRCASA. We extracted from them the main scientific knowledge and data to report the State-of-the-Art and traditional and new practices used to restore the soils. We searched in SCOPUS the papers with three keywords: Restoration, Soil, and Mediterranean. From the 192 papers found, we compiled the basic ideas and information shown here. We expanded the review to other papers that contribute with information about soil restoration but did not mention in the keyword list. Next to the peer-reviewed paper, a set of project reports was reviewed. Most of the project reports are very wide in terms of topics and geographical spread. Therefore, we selected the sections related to the Mediterranean, and soil degradation issues. We found overlap and repetition in the project reports as they use similar or the same sources of information.

A list of projects and institutional reports and web pages were reviewed:

4 per 1000 - Soils for food security and climate. https://4p1000.org/

AGFORWARD - AGroFORestry that Will Advance Rural Development. https://www.agforward.eu

CASCADE – Catastrophic Shifts in Drylands: How can we prevent ecosystem degradation? https://cordis.europa.eu/project/id/283068

CIRCASA EIP-AGRI - The agricultural European Innovation Partnership. https://ec.europa.eu/eip/agriculture/en/european-innovation-partnership-agricultural

EJP SOIL – Towards climate-smart sustainable management of agricultural soils. https://ejpsoil.eu

ESP - European Soil Partnership. https://www.europeansoilpartnership.org

GSP – The Global Soil Partnership for Food Security and Climate Change Adaptation and Mitigation. https://www.iaea.org/about/partnerships/other-international-organizations/gsp

INSPIRATION - INtegrated Spatial Planning, land use and soil management Research AcTION. https://cordis.europa.eu/project/id/642372

IPBES - Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://www.ipbes.net

ITPS - Intergovernmental Technical Panel on Soils. https://publications.jrc.ec.europa.eu/repository/handle/JRC93585

JRC – The Joint Research Center. https://commission.europa.eu/about-european-commission/departments-and-executive-agencies/joint-research-centre_en

Landmark - European Research Project on the sustainable management of land and soil in Europe. https://cordis.europa.eu/project/id/635201

LANDSUPPORT - Development of Integrated Web-Based Land Decision Support System Aiming Towards the Implementation of Policies for Agriculture and Environment. https://cordis.europa.eu/project/id/774234

RECARE - Preventing and Remediating degradation of soils in Europe through Land Care. https://cordis.europa.eu/project/id/603498

SoilCare – SoilCare for profitable and sustainable crop production in Europe. https://www.soilcare-project.eu

UNCCD - The United Nations Convention to Combat Desertification. https://www.unccd.int/convention/overview

LEDDRA – Land and Ecosystem Degradation and Desertification: Assessing the Fit of Responses (LEDDRA). https://cordis.europa.eu/project/id/243857

Figure 4. View of two agriculture regions in Europe. To the left, are the vineyards on steep slopes in the Rhine and Moselle. To the right, is the hay production in the Netherlands. European agriculture must find solutions to different environmental problems such as soil erosion in vineyards and the abuse of fertilizers in meadows and cereals production. Agriculture produces food but also contributes to other services such as a rich landscape, clean air and water, and landscapes that contribute to the health of the planet and the inhabitants

3 A Pan-European approach based on the EU projects, and scientific literature review with comments to the Middle East and North African region

Over the last five years, the European Union developed a program to achieve sustainability in agriculture soil management. The EJP SOIL "Towards climate-smart sustainable management of agricultural soils" (2020-2025), is a program that will enhance the contribution of agricultural soils to achieve climate change adaptation and mitigation, sustainable agricultural production, ecosystem services provision, prevention and restoration of land and soil degradation, and biodiversity maintenance. Upon their reports, we can find State-of-the-Art of soils in Europe. The review of the reports informs about the current situation as was found based on a set of stocktakes done in the 24 countries that are participating in the EJP SOIL. The results can be summarized as i) the data available is not harmonized and shows flaws due to the lack of long-term measurements, and the representation of the different ecosystem and agriculture regions of Europe; ii) there is a need to collect data to build a clear picture of the complex agriculture mosaic of Europe, and a program of measurements, experiments, and monitoring is necessary for the next decades; iii) the use of sustainable management is right now more a plan, a wish, or a dream, more than a reality.

There are many initiatives and pioneers' farmers and scientists working on the new agriculture, but still, there is a lack of contrasted and evaluated strategies to be used. Then, their application in the field should be tested at plot scale and out scaling their use. This is the main challenge for the near future to achieve sustainable agriculture in Europe.

The EJP SOIL reports show that Conservative soil tillage with no-till is the most applied strategy, but in general, most of the fields are ploughed. Values of 4,7 % in Italy show that conservation tillage practices are rare in Mediterranean Europe. Moreover, the use of no-tillage induces an abuse of herbicides that finally results in high erosion rates and soil degradation. An example is the case of Spain where the use of herbicides and no-till expanded and now is the most used (Paz et al., 2021). However, many researchers found that herbicide use contributes to reducing the soil infiltration capacity and increases runoff and soil losses and promotes the degradation of the soil due to the lack of vegetation cover (Di Prima et al., 2018; Keesstra et al., 2019; Cerdà et al., 2021). The use of herbicides also damages human and biota health and diversity (Piñar-Fuentes et al., 2021: Tyohemba et al., 2021), although the multiple factors that determine soil quality make it difficult to identify the cause.

Table 1. Conservation soil tillage practices. Data extracted from Paz, A., Vervuurt, W., de Haan, J., Spiegel, H., Carranca, C., Miloczki, J., ... & Vicente, C. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 2.1 Synthesis of the impacts of sustainable soil management practices in Europe. European Joint Programme Soil. 80 pages

Country	**Conservative soil tillage practices**
Austria	No-till in 2% of cropland and non-inversion in 30%
Denmark	2% no-till; 18% non-inversion 16%; reduced tillage
Eslovenia	2% no-till; 14% non-inversion/reduced tillage
Italy	4.7% no-till
Lithuania	10% all conservation tillage
Norway	Minimum 1.2 % and maximum 17 % in 2000-2017.
Slovakia	Potential estimated of 25% (no statistics for actual area)
Spain	43% reduced till in woody; 65% no-till and reduced till in vineyards; 52% no-till and reduced till in olive; 21% no-till and reduced till in cereal crops and crop rotations
Sweden	25% reduced tillage in Southern Sweden (NEM and CON); ~1% no-till
United Kingdom	45% of farms use some form conservation tillage

Figure 5. Many regions of the world are quickly developing soil restoration programs. To the left, use of cover crop is Barossa Valley vineyards near Adelaide in Australia. To the right, organic local production in The Netherlands (Wageningen)

The cropping practices in each country depend on the climate, lithology, slope angles, and mainly on the tradition of farming. The data supplied by the EJP reports show that there is little information in many countries within the European Union to write a consistent report. The EJP report by Paz et al. (2021) accounts for 4 countries (Austria, Slovenia, Sweden, and Portugal) with information about the cropping systems. Some of the crops are catching/cover crops, permanent grasslands, buffer strips, crop rotations, and agroforestry (see Table 2). The literature review shows a lack of an inventory of cover crop practices in Europe and shows that most of the research focuses on effect, characteristics, ecosystem services, crop protection, crop rotation, alley cropping, or farmer`s perception (Quinkenstein et al., 2009; Kernecker et al., 2020; Ditzler et al., 2021).

Table 2. Country cropping practices. Data extracted from Paz, A., Vervuurt, W., de Haan, J., Spiegel, H., Carranca, C., Miloczki, J., ... & Vicente, C. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 2.1 Synthesis of the impacts of sustainable soil management practices in Europe. European Joint Programme Soil. 80 pages

Country	**Cropping practices.**
Austria	~20% for cover/catch crops
Slovenia	~66% Permanent grassland
Sweden	~45% of annual crops with grass buffer strips
Portugal	~31% of area subject to crop rotation under CAP rules, “biodiverse pastures" >500000 ha in 2010, and agroforestry systems in 8.8% (781 517 ha of the total area in 2010)

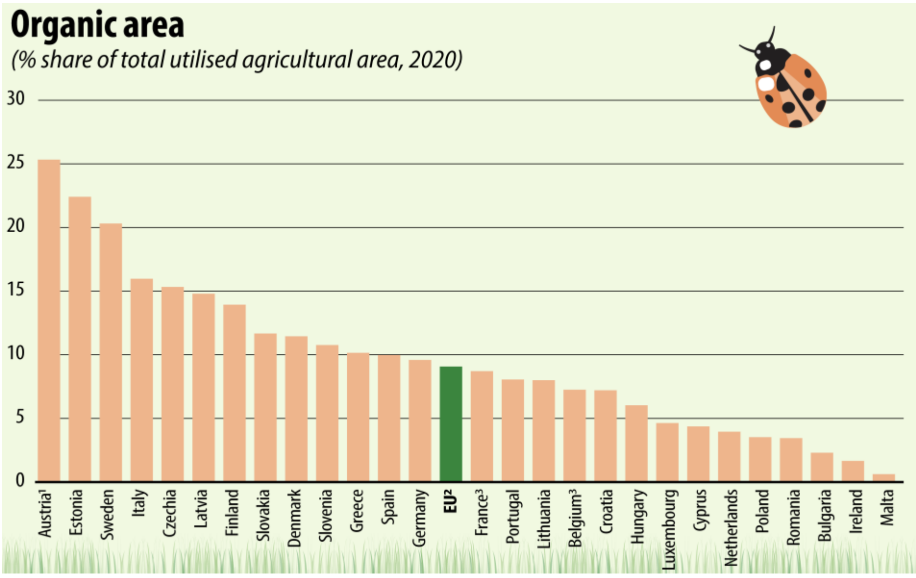

Figure 6. Organic farming by counties in Europe. By https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Organic_area_2020.png

The management of nutrients is relevant to achieve sustainability as they must be recycled. Currently, Europe has based its agriculture on synthetic fertilizers that create problems due to the greenhouse gas emissions and soil and water pollution (Walling and Vaneeckhaute, 2020; Garske et al., 2020; Klages et al., 2021). The European Union is promoting the use of organic farming with restrictions on chemical farming and also with subsidies to organic farming. Austria has 25 % of its land on organic farming management, but this is an exception in comparison to other countries. The total area under organic farming in the EU continues to increase, and in 2020 covered 14.7 million hectares of agricultural land. The growth from 2012 till 2020 was 55.6 % and reached the organic area made up 9.1 % of total EU agricultural land in 2020. Those are good news due to the increase in organic farming in Europe, but there is a need to accelerate the transition to more sustainable agriculture. Sweden, Estonia, and Austria achieved more than 20 % of their agriculture under organic farming management. However, Luxemburg, Cyprus, The Netherlands, Poland, Romania, Bulgaria, Romania, and Malta do not reach 5 % of their agricultural land. The Mediterranean countries contribute with values around 10 %, with Italy reaching 16 %. The lower industrial development of the Mediterranean contributes to areas free of pesticides and available for organic farming. In the north of Europe, the environmental conditions and the traditional fertilization of the land reduce the chances to achieve organic farming management.

In general, the scientific community accepts that organic farming brings clear benefits for the health of the soil and the planet as it mitigates air, soil, and water pollution (Martinho et al., 2019). However, there is a risk to reduce food production and contribute to a global food security threat such as the Russia-Ukraine war has shown (Ben hassen and El Bilali, 2022). Other authors found that the changes to organic-based agriculture will induce a shortage in food availability and will contribute to a less food-secure world. Beckman et al., (2020) showed that the European Commission Farm to Fork and Biodiversity Strategies would reduce the use of fertilizers and this will result in a decrease in agricultural production by 7 to 12 percent, which would increase the food prices by 9 percent. The higher food prices under these scenarios would increase the number of food-insecure people in the world's most vulnerable regions by 22 million if the EU policies will be implemented successfully.

The Middle East and North-African countries agriculture received much less attention than the studies related to soil conservation. Nonetheless, the results are like the ones found in the Mediterranean region of Europe. The problems of overgrazing are still a problem in North Africa and the Middle East. In the North of Africa, there is information about land degradation In Morroco, the degradation of the soils has been certified by El Mekkaoui et al., (2023), Braim et al., (2020), and Sadiki et al., (2009). Similar results were found in Argelia (Tairi et al., 2021), Tunisia (Serbaji et al., 2023), and Egypt (El Baroudy, 2011). There is almost no information about Libya, Mauritania, Djibouti, or Sudan. In the Middle East, most of the information about land degradation arrives from Israel and Turkey (Goldshleger et al., 2010; Nachshon, 2020; Salata and Thompson Couch, 2022). Most of the other countries show a little contribution to the knowledge of soil degradation. The restoration of degraded soils has been mainly studied in Israel which shows an advanced science (Dor-Haim et al., 2023).

Figure 7. Organic farming in Fontanars dels Alforins, Eastern Iberian Peninsula. Organic farming is very positive for soil restoration. However, some organic farms still remove the pruned branches and burn them instead of chipping the branches to recover organic matter and reduce soil and water losses. Policies must be updated to promote a more sustainable management in European soils. A bare soil is prone to be eroded, and biodiversity, soil structure and soil water retention is reduced

Table 3. Nutrient management. Data extracted from Paz, A., Vervuurt, W., de Haan, J., Spiegel, H., Carranca, C., Miloczki, J., ... & Vicente, C. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 2.1 Synthesis of the impacts of sustainable soil management practices in Europe. European Joint Programme Soil. 80 pages

Country	Nutrient management
Austria	25% area (21% farms) in organic farming
Germany	About 60% of all arable land is fertilized organically because specialization and the spatial separation of livestock farms and market fruit farms continue to progress. In regions dominated by market fruits, such as eastern Germany,

	only about 40% of all arable land is fertilized organically. Other organic fertilizers are only available in limited quantities. Only 1 to 2% of arable land can be supplied with compost.
Norway	Approximately 34% of N and 58 % of P applied to agricultural soils originates from manure. The total fertilizer usage decreased by 35%
Portugal	7% area in organic farming

Another key issue for the sustainability of agriculture is the use of water. Irrigation increases productivity but induces changes in the soils that often contributes to their degradation. This issue is very important to look in to especially in Mediterranean countries due to their water deficit, which makes them to have the largest irrigated area in Europe. The EJP soil report by Paz et al., (2021) shows that Spain is the country with most irrigated land, and that drip irrigation now is implemented in 53 % of the irrigated land. Irrigation is also expanding in northern European countries where droughts and new crops require more and more irrigation. Although Fader et al., (2016) claim for more efficient irrigation increases the water requirements, there is a need to find a sustainable management of water, and this is to determine the total surface of that can be irrigated with the available amount of water. Climate change will be one of the key issues (Garrote et al., 2015). The estimated water requirements in Europe are very diverse, and the challenge is to find an agreement to use the water in a sustainable manner. We also lack deep knowledge how to properly manage the water resources in a changing Europe (Wriedt et al., 2009) while we are removing the traditional sustainable flood irrigation by drip irrigation. One example is the use of deserts to produce fresh vegetables with a high demand for water. In the last three decades, the largest increase in agriculture production in Europe took place in Almería (Tout, 1990; Contreras et al., 2021). Almería is the driest region of Europe and the largest producer of vegetables, which shows that irrigation is a key component to achieving sustainability in European agriculture.

Figure 8. Soil erosion is triggered by humans due to ploughing. To the left, persimmon plantation under drip irrigation with intense ploughing and herbicides from Eastern Spain. To the right, intense ploughing in La Mancha wine production areas in Central Spain

Table 4. Water management. Data extracted from Paz, A., Vervuurt, W., de Haan, J., Spiegel, H., Carranca, C., Miloczki, J., ... & Vicente, C. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 2.1 Synthesis of the impacts of sustainable soil management practices in Europe. European Joint Programme Soil. 80 pages

Country	Water management
Austria	1.5-2% area is irrigated
Czech Republic	The drainage area covers as much as a third of currently or formerly agricultural managed land, measured as a surface area of ~1.1 mil. Ha.
Denmark	11% of the cultivated area was irrigated in 2018, mainly located in the western part of the country.
Slovenia	1.7% of the cultivated area was irrigated in 2018 (3200 ha), located in the eastern part of the country and in the western part.
Spain	The largest irrigated area in Europe with 3.828.747 ha. Drip irrigation is applied in 53%; surface irrigation in 24%; sprinkler irrigation in 15% and other forms or pressurized irrigation in 8%. All types of crops are irrigated, from field crops mainly irrigated by central pivots to intensive horticulture mainly irrigated with drip localized systems. Irrigation is one the main drivers of N leaching and this is in part because irrigation scheduling decision-making is still often and fundamentally tied to the local grower's experience. When water availability fails to meet a crop's requirements, irrigation can be scheduled by partial root zone drying strategies irrigation system. Alternatively, irrigation can be reduced during the entire crop growing period (deficit irrigation) or only in those phonological stages in which yield is relatively less sensitive to soil water deficits (regulated deficit irrigation).
Sweden	About 30 % of the agriculturally used land is naturally drained, while 50% are drained artificially with a subsurface drainage system. Irrigation is limited to Southern Sweden and occupies an area of less than 100 000 ha.
Portugal	About 13% of the agricultural area is irrigated (~462 000 ha) (data from 2014)

European subsidies to invest in the drip irrigation system were key to supporting the shift from a traditional rainfed and irrigation (flooding) agriculture system to a drip-irrigated one. This induced a loss of the traditional heritage in Mediterranean agriculture and the degradation of the soils as a consequence of the bare soils, pesticides and monoculture, that were enhanced by drip irrigation. A human impact of the new agriculture is the loss of the rural population because of aging and the mechanization of the farms. There is also a loss in the traditional structure of the landowners as large new companies are colonizing the best lands and degrading the cohesion of the farmer communities. This can be seen in the traditional irrigation communities based on flooding, which are not any more communities with a word in the management.
Next to that drip irrigation also negatively effects the groundwater resources as groundwater is over-exploited through wells that pump water. As a result, the groundwater table has been lowered which caused the loss of springs that use to supply surface runoff to the traditional field-irrigated orchards. It is important to realize that the traditional flood irrigation was using water resources in a sustainable way: i) the water used was provided by natural springs that delivered the water without over using it; ii) the water that was not used by the irrigation system returned to the groundwater through percolation or flowed along the drainage system and finally to the river; iii) the system runs by gravity and does not use any fossil fuels for pumping water, as fuel, diesel and electrical pumps are very popular.

Figure 9. Monoculture induces high erosion rates, loss of biological diversity, soil degradation, and loss of the traditional mosaic of Mediterranean agriculture. Vineyards in Extremadura (Tierra de Barros) where Jesús Barrena kindly exert as scale

4 Soils as a key actor in climate change mitigation. The role of organic matter and soil erosion

A key topic in all the scientific reports provided by EU-funded projects is the carbon cycle and the importance of the soil system. This is due to the rapid change in climatic conditions and its impact on the European economy and society. The reports reviewed agree that soil can be the solution, or at least, can contribute to reducing atmospheric carbon by sequestering carbon in the soil (Smith, 2004; Powlson et al., 2008). Carbon sequestration in soils is a counter act carbon emissions and reduces global warming. Soils store 2,344 Gt C of carbon as soil organic carbon that can be stored for millennia. The soil carbon can remain stored in the soil for thousands of years and therefore soils constitute the largest terrestrial carbon pool. Healthy soils are seen as a solution to mitigate global warming as the restoration of soils contributes to an increase in organic matter. Today, climate change adaptation and mitigation are based on soil restoration. Soils are not anymore only the source of food; they are now understood to make a significant contribution to managing future climatic conditions. And beyond, soils are key to advance in the Sustainable Development Goals of the United Nations (SDGs). Organic carbon sequestration is now a key contribution of soils to the health of the Planet, and the EU promotes research to better understand the carbon cycle in soils and to promote the increase in them (Keesstra et al., 2016).

Figure 10. Two examples of the cause of soil degradation in the Mediterranean. To the left, the litter is being burnt to keep the soil "clean and tidy" in La Ribera district (L'Énova municipality) in Valencia region. To the right, overfertilization of peaches with drip irrigation (fertilization with the irrigation) and solid fertilizers rich in nitrogen (white product on the soil surface)

The important role of soils in the Earth System is now accepted more widely which is reflected by the many new policies and initiatives that, have been, and are being developed to achieve a sustainable world. At the European Union, the European Green Deal (EGD) also watches into the soil contribution as a solution to shift European policies into sustainable management. The key policy tool related to soil is the new Mission 'A Soil Deal for Europe'. In a document that predeceased the Mission, a document was released by Veerman et al. (2020) that was called "Caring for Soil is Caring for Life" which reflected thoughts of the Mission Board on Soil Health and Food. In this document one of the main targets that was set was a minimum of 75% of all soils in Europe must be healthy by 2030 and they must be able to provide essential ecosystem services. Based on this document the current Mission of a Soil Deal for Europe is based. This Mission has as its main target to establish 100 living labs and lighthouses by 2023. There are 8 specific objectives and 4 operational objectives defined by the mission. Two of these specific objectives relate directly to the topic of this report: i) specific objective 1, reduce Desertification, and Specific; ii) objective 5, Reduce erosion. But also, specific objective 2 (conserve soil organic carbon stocks) is an important element to see in the context of this report. Moreover, the 4 per 1000 Initiative is a good example of the central role of soils (Vermeulen et al., 2019). The target is that the "current carbon concentration losses on cultivated land (0.5% per year) must be reversed to an increase by 0.1-0.4% per year". This will contribute to achieving the UN Sustainable Development Goals (SDGs) and land degradation neutrality in the EU by 2030 (EU Green Deal). Moreover, soils will play an important role via climate change (Climate Law), environmental protection (Biodiversity strategy), and

agricultural policies (CAP, Farm to Fork strategy). Soils are playing a central role in the future of Europe and their restoration is relevant for the fate of the economy, society, and nature in the European Union.
The Green Deal EU policies discussed above aim to increase the organic carbon in soils and there are managements that can help: conservation agriculture, residue management, mulches, cover cropping, agroforestry, biochar application, restoration of degraded soils, control soil erosion, are some of the increasing soil organic carbon stocks strategies (Dawson and Smith, 2007; Powlson et al., 2012; Beillouin et al., 2022). The increase in organic matter in soils will reduce the CO_2 in the atmosphere, but the challenge of carbon sequestration is even larger as climate change (global warming) is at the same time accelerating the organic matter decomposition (Steinmann et al., 2016). But sequestering carbon in soils is possible to achieve as was shown by other researchers, who found an increase in soil organic matter in soils when treatments such as land abandonment (Cerdà et al., 2018) or organic farming (Novara et al., 2019) show a clear recovery of organic matter in the soil surface and an increase in agriculture services (Novara et al., 2017).
The review of the EU research project reports and the scientific literature shows that there are gaps in knowledge due to: i) lack of long-term measurements; ii) lack of measurements in deep layers (>20 cm); iii) little knowledge about the impact of climate, management, and land use. For the Mediterranean region of Europe, the main gaps are the lack of research on deep soil carbon and its dynamics impacts of deep roots on C stocks and the use of biochar and its potential. The EJP Soil project research also highlights for the south of Europe the need for modelling of soil organic matter, the need to standardize an international method to measure the carbon stock in soils, and the potential sequestration of carbon by the soils. There is also a need for long-term measurements, bulk density measurements, and quality of the organic matter. The reports are more a list of unknown issues than known evidence and findings (Bai and Cotrufo, 2022; Galón-Martín et al., 2022).

Figure 11. View of the Andalusia olive groves. To the left, the abuse of herbicides removes all the weeds, and the soil is bare. To the right, use of grass strips in olive plantations. The subsidies of the European Union are very positive for the Mediterranean crops, but farmers only apply the alternatives managements to receive the payment of the subsidy and not because they believe in them

A key issue in the recovery of soil organic carbon is the contribution of the stakeholders. The CIRCASA research project report agrees that "while there is a considerable private and public interest in soil carbon and health, adoption of soil enhancing agricultural practices appears to be slow". The fact that farmers see the new strategy as the cause of additional costs, lack of funds for new machinery, and absence of farm extension services, results in a barrier for adoption of the new management that could enhance soil organic carbon. We need in Europe to strengthen the knowledge base and re-install good independent (not paid by agro-chemical industry) farmer advisory services, improved public awareness, and improve the way we approach scientific knowledge (indicators). The agricultural transition needs to be fostered by a good and profitable subsidized carbon farming system. The Mediterranean countries face even more problems: the high temperatures promote carbon decomposition; soils are very degraded already and their ability to recover the organic matter will need a significant shift in management. In addition, most farmers are relatively old and have a low technical education. Aging is a problem in rural areas to change the management of the agriculture land. All these factors make the recovery of the soil organic matter in the Mediterranean a challenge. The CIRCASA project proposed a Strategic Research Agenda (SRA) derived from a multi-stakeholder, multinational, interdisciplinary inventory that included a range of interested parties and a variety of relevant institutions.

In Europe, Borrelli et al., (2018) studied the extend of the problem of soil erosion. They found that within soil erosion there is on-site soil loss and off-site impact of sediment transfer through the landscape. Water erosion at the European scale was estimated at 4.62 Mg ha^{-1} y^{-1}, of which 93.5 % of the sediment yield originates from agricultural land. Soil erosion is also responsible for 14.5 Tg y^{-1} of organic carbon transported from Europe. Virto et al., (2014) described the main chemical, physical and biological degradation of soil in Western Europe. They conclude that no single soil management strategy is suitable for all regions, soil types, and land uses. This means that our soil management in Europe must be adapted to each area.

The review paper by Cerdan et al., (2010) shows that 81 experimental sites in 19 countries with 2741 plot-year measurements resulted in averages of 1.2 Mg ha^{-1} y^{-1} in covered land and 3.6 Mg ha^{-1} y^{-1} in arable land. The highest soil erosion rates were found in vineyards, and although the soil highest soil erosion rates were not found in the Mediterranean, the shallow soils of the Mediterranean climate should be protected to preserve the soils to contribute to the preservation of the ecosystem services these fragile soils provide. Another key research in Europe is the paper of Vanmaercke et al. (2012) that compiled annual sediment yield data for 1,794 catchments and 29,203 catchment-years of observations demonstrated the importance of erosion processes other than inter-rill and rill erosion for catchment-scale sediment yields, in particular gully erosion, channel erosion, mass movements, and glacial erosion. Using modelling Bosco et al. (2014) applied the Revised Universal Soil Loss Equation (RUSLE) and found that 130 million in Europe are being affected by soil erosion. Almost 20% was subjected to soil loss in excess of 10 Mg ha^{-1} y^{-1} (EEA, 2012). The average rate of soil erosion by water across is estimated in 2.76 Mg ha^{-1} y^{-1}, and again they found the soil erosion in the Mediterranean was higher (3.1 Mg ha^{-1} y^{-1} versus 1.7 Mg ha^{-1} y^{-1}). In another modelling study Kirkby et al., (2004) by means of the PESERA model found that 105 million ha or 17% of the total land area of Europe is affected by some degree of soil erosion. They found that the southern zone of Europe (Mediterranean) is the one with the highest soil erosion rates, and Greece, Italy, Portugal, Italy, and Spain show the highest soil erosion rates. Therefore, REACT4MED contributes to finding sustainable soil management that will reduce the extreme soil losses in southern Spain and Portugal, but also in Morocco or Turkïye.

Figure 11. Soil erosion in vineyards and almonds (Fontanars del Alforins and Font de la Figuera, Eastern Iberia Peninsula). The current management of Mediterranean soils force the productivity with intense ploughing or abuse of herbicides. Soil degradation is widespread in agriculture land

5 Soil degradation. What is accepted? Looking forward solutions for agricultural land

There are some general and accepted truths about soil degradation. Other issues are under discussion. We agree that degraded soils have a lower capacity to provide services to humans and that yet day by day we have more degraded soils due to unsustainable management from 15% in 1991 to 25% in 2011. We also agree that one-third of the land is currently moderately to highly degraded. Another agreement is that we must urgently restore the degraded lands with new management and changes in land uses. The research projects developed in Europe agree that soil erosion is the main driver of soil degradation, especially in the Mediterranean. But, there are others that threat the Mediterranean sustainability.

Seventeen percent (115 million ha) of Europe is at high risk of soil erosion, and most of his land is used for agriculture. Another, well accepted fact is that severe erosion is found in the south (Mediterranean), with much lower risk in the north, both, west and east. The largest soil erosion rates are found in Spain, Greece, Italy, and Portugal.

Next to erosion also other degradation processes are important. Soil compaction is found in one-third of the soils usually caused by heavy machinery, soil contamination with heavy metals, acidification, eutrophication, and pollution due to the more than 400000 tones of pesticides used in agriculture, soil organic matter decline, salinization, and soil sealing. All those factors contribute that in the Mediterranean region, Desertification takes place.

Climate, and climate change, are key factors of soil degradation. In a (semi)-arid climate, the soil is more prone to degradation (Ruiz-Sinoga and Diaz, 2010) due to poor vegetation cover and low and easily degradable organic matter content. Other natural causes are the steep relief and soft parent material that is prone to soil erosion (Salvati et al., 2011; Djuma et al., 2017). However, our literature review shows that behind most soil degradation processes we can find the hands of humankind. This means, that we must pay more attention to the role of society, culture, economy, and management in soil degradation (Salvati et al., 2015).

The EJP-SOIL highlights that soil degradation should be reversed to: i) to improve soil fertility and ii) enhance soil quality to restore soil health. According to FAO (2015) European soils lost 7.9% of their fertility in the 20th century. Soils diminished their capacity to promote food security, climate mitigation, and provision of ecosystem services. They agree that within the UN Sustainable Development Goals Europe must reach Land Degradation Neutrality (UNCCD), and sustainable agriculture is relevant for this purpose. They published a document in 2019 called the Voluntary Guidelines to Sustainable Soil Management. The best tool to accomplish this objective is to change the agriculture soil management with i) crop diversification; ii) permanent soil cover by means of perennials, cover crops, and/or leaving crop residues on the field (mulching); iii) addition of organic amendments; and iv) agroforestry. There is also other landscape management that can help to restore the soil quality: i) vegetation strips; ii) mixed farming; iii) improving advanced technology; iv) improving grazing.

Figure 12. View of citrus plantations under No-Tillage in the municipality of Montesa, Iberian Peninsula. To the left a 5-year-old plantation under no-tillage. The bare soils will contribute to extreme soil erosion rates. To the right, is the preparation for the plantation of the new orange saplings. The soil preparation for the new plantation results in soil erosion and soil compaction, and this also contributes to high erosion rates after the plantation when the crop and weeds cover is negligible. The Montesa study sites are used by the REACT4MED PRIMA research project

5.1 Project objectives

Among the different strategies to apply crop diversification, crop rotation is the most known. The succession of different crop species in some fields is well known in Europe with cereal and pulses. In the Mediterranean, the use of legumes was adopted (Oliveira et al., 2019) in rainfed agricultural land. The rotation strategy is also now applied in irrigated orchards and gardens (Kayikcioglu et al., 2020) with success. The well-known and traditional research by López-Bellido et al., (1996) about crop rotation and their contribution to soil fertility (N) is now moving to more sustainable agriculture without chemical fertilizers (Mas and Verdú, 2003). The impact of rotation also contributes to a more diverse fauna, and effectively prevents pests of insects (López-Fando and Bello, 1995). Crop rotation was also found very useful in the Mediterranean, including the arid lands (Jacobsen et al., 2012).

Another type of crop diversification is intercropping, which consists of more than one crop being cultivated in the same field. The use of intercropping was found successful in vineyards (Mercenaro et al., 2014) although the competition for water and nitrogen is high (Celette et al., 2009). The most widespread intercropping management type is the combination of cereal with pulses such as the one Yilmaz et al., (2008) studied in Turkiye with maize and legume. Intercropping in orchards is being tested in citrus plantations (Cerdà et al., 2021; Martin-Gorriz et al., 2022) in the western Mediterranean region. Latati et al., (2017) found that common bean enhances microbial carbon and nitrogen availability in maize crops in the Mediterranean. Similar results were found by Salama et al., (2022). Vineyards are more and more intercropped (Ripoche et al., 2011).

Our review found that although in general there is a positive effect of intercropping, there is a need to study this management in different climates, soil types and crop types in addition to measuring the long-term effects in different crops, and regions. We advocate also that the term crop diversification should be studied from different perspectives, from plot to regional scale, and that more research is necessary to define a more sustainable land planning as we need to change the monoculture of many regions in the Mediterranean to a more diverse agriculture production.

Figure 13. New plantations of oranges contribute to accelerating soil degradation in the Mediterranean. The European Union subsidises (CAP) the new plantations. Most of the European Union subsidies aim to make agriculture more environmentally friendly, but the way how the funding is applied can contribute to soil degradation. Therefore, it is essential to assess trade-offs of each subsidized management

5.2 Organic amendments

The use of organic amendments is well-known in the Mediterranean gardens where an intensification of agriculture was developed for centuries and generated new irrigated and highly productive landscapes (Martí and García-Mayor, 2020). The Green Revolution induced the use of chemical fertilizers. Then, the use of manure was abandoned in the Mediterranean. This is also related to the loss of livestock on the farms. The specialization and industrialization of Mediterranean agriculture transformed traditional organic fertilization into a chemical one. The use and abuse of chemicals degraded the soils and water and for their restoration organic compounds are necessary.

Diacono and Montemurro (2010) reviewed the impact of organic amendments on soil fertility, and they found an increase in the nutrients, organic matter, lower soil bulk density and stronger aggregates, and soil physical properties with more soil microbes. The amendments and the doses are the key factors in the soil properties recovery, but in general, the recovery is low and takes long periods of time.

The research of González-Ubierna et al. (2012) showed that high doses of organic amendments are necessary to restore Mediterranean calcareous soils. Different amendments have been used with success such as coffee grounds (Cervera-Mata et al., 2018), compost, and sewage sludges (Romanos et al., 2019; Monti et al., 2021; Picariello et al., 2022). The main impact of organic amendments affects the nutrients available (Criquet and Braud, 2008) but also on greenhouse gas emissions, grape yield, and soil properties (Marín-Martínez et al., 2021), soil fertility (Siles et al., 2014; Scotti et al., 2015) or nitrogen enrichment (Antoniadis, 2013). The research of Larney and Angers (2012) already contributed to the basic knowledge of the effects of organic amendments, which are of help to achieve sustainable management. However, the doses and the materials for different agricultural regions in the Mediterranean should be defined on the basis of sustainability.

Organic amendments reduce soil erosion as they favor higher infiltration rates and less runoff. They also contribute to restoring land affected by excessive salinity and/or sodicity as more organic matter will contribute with higher cation exchange capacity, the effect on pH, and the improved soil physical properties favoring infiltration and reducing the surface wash and then the ºsoil erosion rates (Cerdà et al., 2022).

Figure 13. Soil erosion and Mediterranean agriculture are twins. Soil erosion in almonds and cereal crops in the Les Alcusses Valley

5.3 Covers

Nature protects soils with a cover of litter and plants (Carson, 2002). Agriculture used the plow to prepare the seedbed and to plant and remove the weeds. During the 20th century the use of herbicides induced the spread of bare and crusted soils. Bare soils contribute to higher runoff generation (Cerdà et al., 2016; Keesstra et al., 2016). The lack of vegetation cover and litter also disturbed the organic matter turnover, the habitat for biota, and the physical and chemical soil properties. This is the current situation in most of the agricultural land in the Mediterranean. Soils are bare, plowed, or disturbed using herbicides.

There is a need to restore the vegetation and create a cover. Different strategies can be used to cover the soil. The use of perennials is a good option to maintain the soil covered as a grassland or meadow. Another option is to sow cover crops or use crop residues. Any of those covers will contribute to reducing soil loss as it increases the surface roughness, increases infiltration, reduces runoff and erosion, and reduces soil compaction.

Perennial covers contribute to an increase in soil organic matter and improve the soil infiltration in soils affected by soil degradation because of poor agriculture management (Jez et al., 2021). In the Mediterranean ecosystem, the use of perennial covers contributes to mitigating soil erosion (Cosentino et al., 2015). This is very relevant in the Mediterranean where there are large areas affected by marginal crops (Fernando et al., 2018). However, the summer drought in the Mediterranean risk the perennial cover (Clary, 2008; Volaire et al., 2009). Perennials are being also used in degraded soils for rehabilitation of post-mining sites (Porqueddu et al., 2016).

Using cover crops is another option to manage the soil in a sustainable way, and they are a clever strategy in the Mediterranean to avoid the summer drought. Cover crops contribute to reducing nitrate leaching, reducing salinity, improving soil structure, and increasing organic matter, soil fertility, and soil biodiversity. Rodrigues and Arrobas (2020) also found an increase in fruit production and farming sustainability with the use of cover crops. In the Mediterranean, Novara et al., (2020) found that the cover crops favor an increase in soil organic carbon, nitrogen dynamics, or microbial diversity. Scavo et al., (2021) found that *Trifolium subterraneum* cover crops enhanced soil fertility and weed seed bank dynamics. de Pedro et al., (2020) studied the soil fauna and found that they increase the ground-dwelling arthropods in pear orchards of the Mediterranean. Moukanni et al., (2022) discovered that optimizing carbon sequestration in the Mediterranean agriculture fields was possible with the use of cover crops. The soil remediation by cover crops results in a positive impact to control soil erosion (Novara et al., 2021). Scavo et al., (2020) researched how cover crops improve soil health, weed management, and nitrogen dynamics with the use of *Trifolium subterraneum* cover. The increase of carbon sequestration by the soil is possible when cover crops are applied such as Novara et al., (2021) found in sloping vineyards. López-Vicente et al., (2020) used cover crops to reduce the loss of organic matter in vineyards, and Repullo-Ruiberriz et al., (2021) found that soil nitrogen and carbon sequestration in almond orchards is improved with cover crops and Restuccia et al., (2020) that cover crops increase the species abundance and diversity of weed flora. Catch crops are always positive to improve the soil quality and contribute to sustainable management in agriculture in the Mediterranean.

However, even though research shows that the use of cover crops is very positive, it is rarely implemented by farmers in the Mediterranean. There is a need to improve the scientific and technical knowledge to apply the best cover crops possible, and this requires further investigations. It is urgent to find strategies to convince farmers to use catch crops as right now their perception is negative. Marques et al., (2015) found that winegrowers prefer to have their farms tidy and clean, with no cover crops. Sastre et al., (2017) found similar findings for olive crops, and Cerdà et al., (2017) show the negative perception of farmers to catch crops in Mediterranean rainfed agriculture. Esgalhado et al., (2020) confirmed the above-mentioned findings.

Figure 14. Water and fire. Mediterranean agriculture used and managed all the elements to achieve sustainability. View of the gardens of the Valencia region that produce fresh garlic and tiger nuts. To the left irrigation at the Murta ditch district during the flood of the crop. To the right, removal (by fire) of the tiger nuts leaves. The harvest will be done a few days later

There is a third soil cover that can contribute to reducing soil losses and soil restoration. The use of materials as a mulch such as residues (i.e., chipped pruned branches or chipped wood from timber industries), straw, or geotextiles. The use of straw has been used with success over the last decades and is widely used by pioneer organic farmers. From a scientific point of view, the research shows that crushed maize straw residues improve the soil's biological properties (Teada and Benítez, 2014). However, the cost of using straw as a mulch is high in application, transport, and acquisition. However, straw contributes to reducing the soil losses such as Prosdocimi et al., (2016) measured in vineyards in the Western Mediterranean region, Cerdà et al., (2016) in persimmon plantations, and Keesstra et al., (2019) on citrus plantations. Ros et al., (2003) also showed the positive impact on soil microbial activity in semiarid soils, but there is little research on the impact on soil properties, which in general increase the soil organic matter, porosity, and biological activity, and this contributes to a reduction in soil erosion and water losses.

The cost of the straw and the perception of the farmers were studied by Cerdà et al., (2017) who found that a subsidy is necessary to be used by the landowners to cover the expenses, but also to avoid the negative perception the farmers have about the use of a straw. There is a lack of information about the crop production impact of straw, and this information should be generated in the next few years (Stagnari et al., 2014).

Another strategy to reduce soil and water losses and improve soil properties is the use of geotextiles. They were widely used in road embankments and mining areas (Shao et al., 2014; Broda et al., 2020; Zaimes et al., 2020). The use of geotextiles induced a sharp reduction in soil and water losses such as Giménez-Morera et al., (2010) found in calcareous soils under herbicide treatments.

There are some covers that are used much less but do have good results. The use of chipped pruned branches contributes to a reduction in soil erosion as Cerdà et al., (2018) demonstrated. Novara et al., (2019) also found that the soil quality was improved with the use of chipped pruned branches. However, there is little information on this issue. Another cover that needs more research is the use of rock fragments, as they increase the infiltration rate and reduce soil and water losses. Kosmas et al., (1994) and Danalatos et al., (1995) already demonstrated the impact of rock fragments (stones) on the soil properties and biomass. Rock fragments contribute to increasing the infiltration rates and improve the soil aggregate stability and increase the soil organic matter due to the higher biological activity and can be a key strategy to fight against soil erosion, soil degradation, soil water losses and desertification such as the research of Jean Poesen demonstrate (Poesen and Bunte, 1996; Wijdenes et al., 1997). Vineyards are the most studied crop on this issue of rock fragments. Follain et al., (2012) and Rodrigo-Comino et al., (2017) contribute to this research with significant knowledge to understand the role of rock fragments on water, nutrients, and soil properties, and complete the contribution of Cerdà (2001) on soil erosion and rock fragments and Zhang et al. (2016) with rock fragments and soil hydrological processes confirmed by recent research (Sekucia et al., 2020).

5.4 Agroforestry and land abandonment

Agroforestry involves the use of woody vegetation to recover the soils affected by degradation in agricultural land and obtain ecological and economic benefits. Agroforestry is probably the most efficient restoration strategy as it is a nature-based solution to the soil degradation problem. Recent research contributes to recovering the use of agroforestry. Temani et al., (2021) demonstrated an increase in productivity in olive plantations in drylands. This is an adaptation of the research already developed in fire-affected land by Damianidis et al., (2021). The main contribution of the agroforestry system is to restore carbon sequestration in the Mediterranean, which is a key issue to achieve the restoration of soils affected by carbon losses for millennia. Querné et al., (2017) measured the impact of intercropped alfalfa in walnut trees and confirmed the positive effects, which were found also by Guillot et al., (2021) using the Mediterranean alley cropping agroforestry system. They found that this strategy improved the monocropping system that is widespread in many Mediterranean regions. Mosquera-Losada et al., (2022) review the policies to achieve a European agroforestry policy for arable Mediterranean areas. Lizaga et al., (2020) researched the agroforestry impact on suspended sediment and shown a positive impact. The recent publications demonstrate that the research of Lovric et al., (2018) was right and that agroforestry must be present within the policies of the European Union and must be adapted to the Mediterranean region situation. It is very relevant that the Mediterranean countries will develop agroforestry strategies to reduce soil losses and contribute to the greening of the region.

Figure 14. Agroforestry and land abandonment will result in the restoration of soils affected by degradation processes. View of vineyards in Andalusia on steep slopes. Detail of the soil erosion plots. Kindly, Jesús Rodrigo, Saskia Keesstra and Johannes Ries act as scale

Another trend in the Mediterranean is the abandonment of agricultural land in the mountains which has generally resulted in the recovery of the vegetation cover, the improvement of the soil properties, and the reduction in soil and water losses (Cerdà et al., 2018). In general, land abandonment increases soil organic carbon and improves soil quality as Lasanta et al., (2020) demonstrated in mid-mountains areas of the Mediterranean. Nadal-Romero et al., (2016) measured the recovery of the soil organic carbon stocks in the humid mountains of the Mediterranean. This increase in organic carbon in abandoned soils is demonstrated in mountainous regions where rainfall is high (Bell et al., 2021). Different abandoned crops show a sudden reduction in soil erosion (Barrena-González et al., (2020), and the improvement in soil properties results in an improvement in ecosystem services (Novara et al., 2017).

Although most of the researchers confirm that land abandonment contributes to the recovery of soil properties, reduction in soil losses, and increase in water infiltration due to the revegetation of the abandoned land. However, most of this research has been done in humid mountain terrain but little is known which is the impact on drylands, and pioneer research on these areas doubts the positive impact of land abandonment due to the low recovery of vegetation and the initiation of rilling and gullying that induce a sudden increase in soil erosion and runoff (Romero-Diaz et al., 2017; Rodrigo et al., 2018).

The review of the data found in the EU research reports and the published papers show that both land abandonment and agroforestry contribute to the control of soil erosion and an increase in SOM and nutrients in the soil. There is a need to improve the measurements (number and accuracy) in the field at plot and pedon scale but also to scale this information at watershed and regional scale to better understand the impact of the new management.

Figure 15. Mediterranean agriculture lost the use of animals in the last 50 years as monoculture progressed. Most of the shepherds are retired and the meat and milk production is now concentrated in large “in-door” farms. The recovery of small herds will supply meat and milk of quality and will contribute with fertilizers to achieve a larger surface of organic agricultural land. The herds of goats and sheep are also necessary to create areas of low biomass to control forest fires. We need to listen more to the wise advice of shepherds

5.5 No disturbance and no-tillage

Tillage has been for millennia the only management applied to agricultural soils. Tillage induces the mixture of the soil horizons and disturbs the natural formation. The plow effect induces the oxidation of carbon, degrades the soil structure, induces soil erosion, and reduces the soil water storage capacity (Conant et al., 2007; Rasmussen et al., 1999; Blanco-Caqui et al., 2017). Tillage means soil inversion, bare soils, destruction of the natural structure, removal of roots, dramatic reduction of life, and destruction of natural pores. The No-Tillage (minimum tillage, direct sowing, zero tillage) improves soil health, improves biodiversity, reduces global warming gas emissions, and enhances soil structure. No-Tillage was well accepted in many rainfed cereal productive areas in Europe (Cannell, 1985 Holland, 2004), USA (Allmaras and Dowdy, 1985), and China (Wang et al., 2007). Argentina is a country where No-Tillage was applied with great success (Peralta et al., 2021). Under Mediterranean climatic conditions, Australia and Chile are the leading countries (Freebairn et al., 1993; Martínez et al., 2008) although also No-Tillage is very popular in Brazil (Fuentes-Llanillo et al., 2021).

Figure 16. The recovery of forests to create a proper agriculture Mediterranean mosaic is necessary to restore the soil services. Forests are necessary for the health of humans and for the health of the planet. Soils under forest management are a sink of carbon and contribute to clean air and water. Mediterranean agriculture must understand this and promote the recovery of forests in the areas with lower production and higher risk of soil degradation. We need to find the right planning and find a general agreement with all the stakeholders

In the Mediterranean, the use of No-tillage (NT) is, as in other regions of the world, associated to the use of pesticides. The use of herbicides (mainly glyphosate) to control weeds is the main change once No-Tillage is established, and this induces changes in the soil properties. Ruisi et al., (2014) reviewed the State of the Art of conservation tillage (CT) in the Mediterranean and found that: i) CT became more popular; ii) on cereal crops grain yield the results are contradictory or no differences; iii) NT results in higher yield in dry years, and CT in wet years; and, iv) CT contribute with higher protein content in grain (15.1% versus 14.4 %), which result in an increase in nitrogen fertilization. The increase in nitrogen in conservation tillage induces changes in the arbuscular mycorrhizal fungal communities (Avio et al., 2013). The research on conservation agriculture (no-tillage and herbicides) focussed on the Mediterranean in the fertilization (Vaquez et al., 2019). This pure agronomic view avoided other research such as the impact on runoff and sediment delivery (Raclot et al., 2009), soil organic carbon storage (Álvaro-Fuentes et al., 2014), and soil microorganisms (Lagomarsino et al., 2009). The use of No-Tillage has been under discussion in the Mediterranean and new strategies arise, such as reduced tillage (López-Garrido et al., 2014).

It has been accepted that No-Tillage reduces soil compaction (Cid et al., 2014), increases soil carbon (Mazzoncini et al., 2016), improves soil biodiversity and biomass (Mangalassery et al., 2015), soil porosity (Pastorelli et al., 2013), soil health (Acir et al., 2022), increase infiltration (Castellini et al., 2019) and reduce soil and water losses (Moussa -Machraoui et al., 2010; Cerdà et al., 2020; Cárceles Rodríguez et al., 2021). However, this is only true when CA is not combined with the excessive use of herbicides. The positive effect of no-tillage is now under discussion in Mediterranean groves and orchards since farmers use herbicides to completely remove the vegetation cover. The abuse of glyphosate contributes to bare soils where surface runoff and particle detachment are high and then the soil and water yield reach extreme values (Keesstra et al., 2019; Cerdà et al., 2019; 2021). There is a need to transform the traditional No-Tillage based on chemical farming into organic management where the cover crops and catch crops will protect the soil and induce the recovery of the soil properties.

Figure 16. The use of fire in Mediterranean agriculture land is now being prosecuted. There is a need to research the impact of fire and good practices to maintain a millennia-old heritage

5.6 An overview

Soil is a non-renewable natural and cultural resource that must be protected. Soil contributes to many ecosystem services and play an essential role in the main biogeochemical cycles. Our review of the impact of the Mediterranean agriculture on soils shows that: i) soil and water losses must be controlled to give the soil a chance to recover; ii) covering the soil with mulches or/and covering and catching crops is a wise strategy to restore the main soil properties such as organic carbon, porosity, and biodiversity; iii) organic amendments contribute to faster restoration of the soil; iv) soil protection should be present within the farming objectives as it is the production; v) reduce monoculture and promote intercropping will help to achieve sustainable agriculture; vi) recover the traditional soil conservation techniques such as terraces and traditional flood irrigation systems (sinks of water and soils) is part of the sustainable strategy for soils and to preserve millennia-old landscapes. There are some constraints that are mainly based on societal factors (aging), economic (farmer's income, subsidies), and perception (farmer's prestige) on soil management.
There is also a need within the Mediterranean world to preserve the cultural heritage that contributed in the past to the sustainability of the ecosystems. The use of grazing to preserve open spaces within the forest land contributes to the diversity of the flora and reduces fire risk. The mountain terraces are sinks of soil, water, and carbon and it is necessary to research more on this and develop policies to protect them. The traditional irrigation systems are gardens of high production and manage the water wisely to preserve traditional crops such as paddy fields or vegetables, but they also contribute to managing the floods and drainage of the land when local floods occur. The Mediterranean preserve some unique cultural heritage, including management strategies such as crop rotation and biodiversity of cultivars that need more research and policies to maintain them.

6 Barriers to the new management

The new management faces different barriers to be applied by the stakeholders. The first barrier is the lack of large datasets and, in general, the lack of broad scientific knowledge. There are few long-term measurements on soil erosion, soil carbon changes, and management impact on soil properties, especially for specific crop and agricultural management strategies. However, within the research developed we found that there are barriers to the application of the new management due to the rejection of the farmers. In general, policymakers are in favour to reduce tillage and herbicides and increase the use of catch crops or mulching. In general, there is insufficient expertise on the novel techniques and the familiar long-term management induce farmers to reject the use of the new techniques. Moreover, there is a lack of education for farmers to understand the ecosystem services and the contribution of healthy soils to the sustainability of farming in Europe. In general, farmers see the new policies as a fruit of the decisions done by politicians far away from the field, in offices, with little knowledge about the farm's economic conditions, which is partially true as well. The perception of the farmers is also negative about the use of covers due to three main reasons: they are expensive, they are not well explained by the government, and some farmers do not accept them as they consider any vegetation that is not the crop as "dirt". If the farmers have a positive view towards the new management, it is only because of the subsidies they receive when they implement them.

Figure 17. The Mediterranean landscapes, with a mosaic of crops under irrigation (flooding) and rainfed, is a millennia-old heritage that must be preserved. Some of the techniques and strategies to face environmental challenges can be found in our own cultural heritage, if not lost. To the left, is the millennia-old flood irrigation system in the Xàtiva gardens. To the right, a forest fire in the Pinet municipality allows us to see the millennia-old terraces. Both systems contribute to preserving soil and form sink water and organic matter. The abandonment of agriculture terraces initiates what is called a "geomorphological time bomb" due to the delivery of sediments accumulated over millennia

7 Conclusions

Soil degradation in the Mediterranean is seen as a dramatic environmental threat to the sustainability of human societies and nature. This literature review confirms the threat and the loss of soil services in Mediterranean areas: erosion, salinization, compaction, loss of organic matter and biodiversity are some of the measured impacts of mismanagement of agriculture mainly due to the millennia-old tillage, and in the last century worsened by the abuse in pesticides. The scientific research informs that there are strategies to restore the soil and preserve the rich-traditional landscapes in the Mediterranean by using management strategies such as the use of catch crops, cover crops, mulching, and organic fertilization. Restoring the agricultural soils can be also a solution to fight against global warming as soils can act as carbon sinks, reduce floodings, and increase biodiversity and landscape quality. The main constraints to applying sustainable management are social, economic, and the perception of farmers towards a chemical free agriculture. The policies developed by the EU are very positive to restore soil services, but some well-intended policies can have negative trade-offs. In addition, there are some barriers to expanding sustainable management to the whole community of farmers. There is a need to develop strategies to upscale the management applied and tested to the landscape and overall use by farmers. There is a lack of scientific research in the long-term to determine the impact of the new management and a lack of crop- and climate-specific testing of management effectiveness. It is necessary to develop lighthouse farms and living labs to test the new strategies that will substitute herbicide (traditional No-Tillage) and tillage management in a more sustainable management of the land with catch crops, cover crops, mulches, and inter- and multi-cropping strategies.

Acknowledgements

This work has received funding from REACT4MED: Inclusive Outscaling of Agro-Ecosystem Restoration Actions for the Mediterranean. REACT4MED Project (Grant Agreement No. 2122) is funded by PRIMA, a Programme supported by Horizon 2020, the European Union's Framework Programme for Research and Innovation. For more information about the REACT4MED, please contact info@react4med.eu.

Literature

Acir, N., Günal, H., Celik, I., Barut, Z. B., Budak, M., & Kılıç, Ş. (2022). Effects of long-term conventional and conservational tillage systems on biochemical soil health indicators in the Mediterranean region. *Archives of Agronomy and Soil Science*, *68*(6), 795-808.

Allmaras, R. R., & Dowdy, R. H. (1985). Conservation tillage systems and their adoption in the United States. *Soil and Tillage Research*, *5*(2), 197-222.

Álvaro-Fuentes, J., Plaza-Bonilla, D., Arrúe, J. L., Lampurlanés, J., & Cantero-Martínez, C. (2014). Soil organic carbon storage in a no-tillage chronosequence under Mediterranean conditions. *Plant and Soil*, *376*, 31-41.

Antoniadis, V. (2013). Mineralization of organic-amendment-derived nitrogen in two Mediterranean soils with different organic-matter contents. *Communications in soil science and plant analysis*, *44*(19), 2788-2795.

Avio, L., Castaldini, M., Fabiani, A., Bedini, S., Sbrana, C., Turrini, A., & Giovannetti, M. (2013). Impact of nitrogen fertilization and soil tillage on arbuscular mycorrhizal fungal communities in a Mediterranean agroecosystem. *Soil Biology and Biochemistry*, *67*, 285-294.

Bai, Y., & Cotrufo, M. F. (2022). Grassland soil carbon sequestration: Current understanding, challenges, and solutions. *Science*, *377*(6606), 603-608.

Barrena-González, J., Lozano-Parra, J., Alfonso-Torreño, A., Lozano-Fondón, C., Abdennour, M. A., Cerdà, A., & Pulido-Fernández, M. (2020). Soil erosion in Mediterranean chestnut tree plantations at risk due to climate change and land abandonment. *Central European Forestry Journal*, *66*(2), 85-96.

Beckman, J., Ivanic, M., Jelliffe, J. L., Baquedano, F. G., & Scott, S. G. (2020). *Economic and food security impacts of agricultural input reduction under the European Union Green Deal's Farm to Fork and biodiversity strategies* (No. 1473-2020-1039).

Beillouin, D., Cardinael, R., Berre, D., Boyer, A., Corbeels, M., Fallot, A., ... & Demenois, J. (2022). A global overview of studies about land management, land-use change, and climate change effects on soil organic carbon. *Global change biology*, *28*(4), 1690-1702.

Bell, S. M., Terrer, C., Barriocanal, C., Jackson, R. B., & Rosell-Melé, A. (2021). Soil organic carbon accumulation rates on Mediterranean abandoned agricultural lands. *Science of the Total Environment*, *759*, 143535.

Ben Hassen, T., & El Bilali, H. (2022). Impacts of the Russia-Ukraine war on global food security: towards more sustainable and resilient food systems?. *Foods*, *11*(15), 2301.

Blanco-Canqui, H., Wienhold, B. J., Jin, V. L., Schmer, M. R., & Kibet, L. C. (2017). Long-term tillage impact on soil hydraulic properties. *Soil and Tillage Research*, *170*, 38-42.
Borrelli, P., Van Oost, K., Meusburger, K., Alewell, C., Lugato, E., & Panagos, P. (2018). A step towards a holistic assessment of soil degradation in Europe: Coupling on-site erosion with sediment transfer and carbon fluxes. Environmental Research, 161, 291-298.
Brahim, B., Meshram, S. G., Abdallah, D., Larbi, B., Drisss, S., Khalid, M., & Khedher, K. M. (2020). Mapping of soil sensitivity to water erosion by RUSLE model: case of the Inaouene watershed (Northeast Morocco). *Arabian Journal of Geosciences*, *13*, 1-15.
Broda, J., Franitza, P., Herrmann, U., Helbig, R., Große, A., Grzybowska-Pietras, J., & Rom, M. (2020). Reclamation of abandoned open mines with innovative meandrically arranged geotextiles. *Geotextiles and Geomembranes*, *48*(3), 236-242.
Brühl, C. A., & Zaller, J. G. (2021). Indirect herbicide effects on biodiversity, ecosystem functions, and interactions with global changes. In Herbicides (pp. 231-272). Elsevier.
Cannell, R. Q. (1985). Reduced tillage in north-west Europe—a review. *Soil and Tillage Research*, *5*(2), 129-177.
Cárceles Rodríguez, B., Zuazo, V. D., Rodríguez, M. S., Ruiz, B. G., & García-Tejero, I. F. (2021). Soil erosion and the efficiency of the conservation measures in Mediterranean hillslope farming (SE Spain). *Eurasian Soil Science*, *54*(5), 792-806.
Carranca, C., Pedra, F., & Madeira, M. (2022). Enhancing Carbon Sequestration in Mediterranean Agroforestry Systems: A Review. *Agriculture*, *12*(10), 1598.
Carson, R. (2002). *Silent spring*. Houghton Mifflin Harcourt.
Castellini, M., Fornaro, F., Garofalo, P., Giglio, L., Rinaldi, M., Ventrella, D., ... & Vonella, A. V. (2019). Effects of no-tillage and conventional tillage on physical and hydraulic properties of fine textured soils under winter wheat. *Water*, *11*(3), 484.
Celette, F., Findeling, A., & Gary, C. (2009). Competition for nitrogen in an unfertilized intercropping system: The case of an association of grapevine and grass cover in a Mediterranean climate. *European Journal of Agronomy*, *30*(1), 41-51.
Cerdà, A. (2001). Effects of rock fragment cover on soil infiltration, interrill runoff and erosion. *European Journal of Soil Science*, *52*(1), 59-68.
Cerdà, A., Franch-Pardo, I., Novara, A., Sannigrahi, S., & Rodrigo-Comino, J. (2022). Examining the effectiveness of catch crops as a nature-based solution to mitigate surface soil and water losses as an environmental regional concern. *Earth Systems and Environment*, *6*(1), 29-44.
Cerdà, A., González-Pelayo, Ó., Giménez-Morera, A., Jordán, A., Pereira, P., Novara, A., ... & Ritsema, C. J. (2016). Use of barley straw residues to avoid high erosion and runoff rates on persimmon plantations in Eastern Spain under low frequency–high magnitude simulated rainfall events. *Soil Research*, *54*(2), 154-165.
Cerdà, A., Rodrigo-Comino, J., Giménez-Morera, A., & Keesstra, S. D. (2017). An economic, perception and biophysical approach to the use of oat straw as mulch in Mediterranean rainfed agriculture land. *Ecological Engineering*, *108*, 162-171.
Cerdà, A., Rodrigo-Comino, J., Giménez-Morera, A., Novara, A., Pulido, M., Kapović-Solomun, M., & Keesstra, S. D. (2018). Policies can help to apply successful strategies to control soil and water losses. The case of chipped pruned branches (CPB) in Mediterranean citrus plantations. *Land Use Policy*, *75*, 734-745.
Cerda, A., Rodrigo-Comino, J., Novara, A., Brevik, E. C., Vaezi, A. R., Pulido, M., ... & Keesstra, S. D. (2018). Long-term impact of rainfed agricultural land abandonment on soil erosion in the Western Mediterranean basin. *Progress in Physical Geography: Earth and Environment*, *42*(2), 202-219.
Cerdà, A., Rodrigo-Comino, J., Yakupoğlu, T., Dindaroğlu, T., Terol, E., Mora-Navarro, G., ... & Daliakopoulos, I. N. (2020). Tillage versus no-tillage. Soil properties and hydrology in an organic persimmon farm in Eastern Iberian Peninsula. *Water*, *12*(6), 1539.
Cervera-Mata, A., Pastoriza, S., Rufián-Henares, J. Á., Párraga, J., Martín-García, J. M., & Delgado, G. (2018). Impact of spent coffee grounds as organic amendment on soil fertility and lettuce growth in two Mediterranean agricultural soils. *Archives of Agronomy and Soil Science*, *64*(6), 790-804.
Cid, P., Carmona, I., Murillo, J. M., & Gómez-Macpherson, H. (2014). No-tillage permanent bed planting and controlled traffic in a maize-cotton irrigated system under Mediterranean conditions: Effects on soil compaction, crop performance and carbon sequestration. *European journal of agronomy*, *61*, 24-34.
Clary, J. (2008). Rainfall seasonality determines annual/perennial grass balance in vegetation of Mediterranean Iberian. *Plant Ecology*, *195*, 13-20.
Colantoni, A., Ferrara, C., Perini, L., & Salvati, L. (2015). Assessing trends in climate aridity and vulnerability to soil degradation in Italy. Ecological indicators, 48, 599-604.

Conant, R. T., Easter, M., Paustian, K., Swan, A., & Williams, S. (2007). Impacts of periodic tillage on soil C stocks: A synthesis. *Soil and Tillage Research*, *95*(1-2), 1-10.

Contreras, J. I., Roldán-Cañas, J., Moreno-Pérez, M. F., Gavilán, P., Lozano, D., & Baeza, R. (2021). Distribution uniformity in intensive horticultural systems of Almería and influence of the production system and water quality. *Water*, *13*(2), 233.Tout, D. (1990). The horticulture industry of Almería province, Spain. *Geographical Journal*, 304-312.

Cosentino, S. L., Copani, V., Scalici, G., Scordia, D., & Testa, G. (2015). Soil erosion mitigation by perennial species under Mediterranean environment. *BioEnergy Research*, *8*, 1538-1547.

Criquet, S., & Braud, A. (2008). Effects of organic and mineral amendments on available P and phosphatase activities in a degraded Mediterranean soil under short-term incubation experiment. *Soil and Tillage Research*, *98*(2), 164-174.

Daliakopoulos, I. N., Apostolakis, A., Wagner, K., Deligianni, A., Koutskoudis, D., Stamatakis, A., & Tsanis, I. K. (2019). Effectiveness of Trichoderma harzianum in soil and yield conservation of tomato crops under saline irrigation. *Catena*, *175*, 144-153.

Daliakopoulos, I. N., Pappa, P., Grillakis, M. G., Varouchakis, E. A., & Tsanis, I. K. (2016b). Modeling soil salinity in greenhouse cultivations under a changing climate with SALTMED: model modification and application in Timpaki, Crete. *Soil Science*, *181*(6), 241-251.

Daliakopoulos, I. N., Tsanis, I. K., Koutroulis, A., Kourgialas, N. N., Varouchakis, A. E., Karatzas, G. P., & Ritsema, C. J. (2016a). The threat of soil salinity: A European scale review. Science of the total environment, 573, 727-739.

Damianidis, C., Santiago-Freijanes, J. J., den Herder, M., Burgess, P., Mosquera-Losada, M. R., Graves, A., ... & Pantera, A. (2021). Agroforestry as a sustainable land use option to reduce wildfires risk in European Mediterranean areas. *Agroforestry Systems*, *95*, 919-929.

Danalatos, N. G., Kosmas, C. S., Moustakas, N. C., & Yassoglou, N. (1995). Rock fragments IL Their impact on soil physical properties and biomass production under Mediterranean conditions. *Soil Use and Management*, *11*(3), 121-126.

Dawson, J. J., & Smith, P. (2007). Carbon losses from soil and its consequences for land-use management. *Science of the total environment*, *382*(2-3), 165-190.Acknoledgements

de Pedro, L., Perera-Fernández, L. G., López-Gallego, E., Pérez-Marcos, M., & Sanchez, J. A. (2020). The effect of cover crops on the biodiversity and abundance of ground-dwelling arthropods in a Mediterranean pear orchard. *Agronomy*, *10*(4), 580

Di Prima, S., Rodrigo-Comino, J., Novara, A., Iovino, M., Pirastru, M., Keesstra, S., & Cerdà, A. (2018). Soil physical quality of citrus orchards under tillage, herbicide, and organic managements. Pedosphere, 28(3), 463-477.

Diacono, M., & Montemurro, F. (2011). Long-term effects of organic amendments on soil fertility. *Sustainable agriculture volume 2*, 761-786.

Ditzler, L., van Apeldoorn, D. F., Pellegrini, F., Antichi, D., Bàrberi, P., & Rossing, W. A. (2021). Current research on the ecosystem service potential of legume inclusive cropping systems in Europe. A review. *Agronomy for Sustainable Development*, *41*, 1-13.

Djuma, H., Bruggeman, A., Camera, C., & Zoumides, C. (2017). Combining qualitative and quantitative methods for soil erosion assessments: An application in a sloping Mediterranean watershed, Cyprus. *Land Degradation & Development*, *28*(1), 243-254.

Dor-Haim, S., Brand, D., Moshe, I., & Shachak, M. (2023). Functional Restoration of Desertified, Water-Limited Ecosystems: The Israel Desert Experience. *Land*, *12*(3), 643.

Dregne, H. E. (1987). Soil erosion: cause and effect. *Land use policy*, *4*(4), 412-418.

El Baroudy, A. A. (2011). Monitoring land degradation using remote sensing and GIS techniques in an area of the middle Nile Delta, Egypt. *Catena*, *87*(2), 201-20

El Mekkaoui, A., Moussadek, R., Mrabet, R., Douaik, A., El Haddadi, R., Bouhlal, O., ... & Chakiri, S. (2023). Effects of Tillage Systems on the Physical Properties of Soils in a Semi-Arid Region of Morocco. *Agriculture*, *13*(3), 683.

Esgalhado, C., Guimarães, M. H., Lardon, S., Debolini, M., Balzan, M. V., Gennai-Schott, S. C., ... & Bouchemal, S. (2021). Mediterranean land system dynamics and their underlying drivers: Stakeholder perception from multiple case studies. *Landscape and Urban Planning*, *213*, 104134.

Fader, M., Shi, S., von Bloh, W., Bondeau, A., & Cramer, W. (2016). Mediterranean irrigation under climate change: more efficient irrigation needed to compensate for increases in irrigation water requirements. Hydrology and Earth System Sciences, 20(2), 953-973.

Fernando, A. L., Costa, J., Barbosa, B., Monti, A., & Rettenmaier, N. (2018). Environmental impact assessment of perennial crop cultivation on marginal soils in the Mediterranean Region. *Biomass and Bioenergy*, *111*, 174-186.

Ferreira, C. S., Seifollahi-Aghmiuni, S., Destouni, G., Ghajarnia, N., & Kalantari, Z. (2022). Soil degradation in the European Mediterranean region: Processes, status and consequences. Science of the Total Environment, 805, 150106.

Follain, S., Ciampalini, R., Crabit, A., Coulouma, G., & Garnier, F. (2012). Effects of redistribution processes on rock fragment variability within a vineyard topsoil in Mediterranean France. *Geomorphology*, *175*, 45-53.
Freebairn, D. M., Loch, R. J., & Cogle, A. L. (1993). Tillage methods and soil and water conservation in Australia. *Soil and Tillage Research*, *27*(1-4), 303-325.
Fuentes-Llanillo, R., Telles, T. S., Junior, D. S., de Melo, T. R., Friedrich, T., & Kassam, A. (2021). Expansion of no-tillage practice in conservation agriculture in Brazil. *Soil and Tillage Research*, *208*, 104877.
Galán-Martín, Á., del Mar Contreras, M., Romero, I., Ruiz, E., Bueno-Rodríguez, S., Eliche-Quesada, D., & Castro-Galiano, E. (2022). The potential role of olive groves to deliver carbon dioxide removal in a carbon-neutral Europe: Opportunities and challenges. *Renewable and Sustainable Energy Reviews*, *165*, 112609.
Galdeano-Gómez, E., Aznar-Sánchez, J. A., & Pérez-Mesa, J. C. (2013). Sustainability dimensions related to agricultural-based development: the experience of 50 years of intensive farming in Almería (Spain). *International Journal of Agricultural Sustainability*, *11*(2), 125-143.
Gardi, C., Jeffery, S., & Saltelli, A. (2013). An estimate of potential threats levels to soil biodiversity in EU. *Global change biology*, *19*(5), 1538-1548.
Garrote, L., Iglesias, A., Granados, A., Mediero, L., & Martin-Carrasco, F. (2015). Quantitative assessment of climate change vulnerability of irrigation demands in Mediterranean Europe. Water Resources Management, 29, 325-338.
Garrote, L., Iglesias, A., Granados, A., Mediero, L., & Martin-Carrasco, F. (2015). Quantitative assessment of climate change vulnerability of irrigation demands in Mediterranean Europe. Water Resources Management, 29, 325-338.
Garske, B., Stubenrauch, J., & Ekardt, F. (2020). Sustainable phosphorus management in European agricultural and environmental law. *Review of European, Comparative & International Environmental Law*, *29*(1), 107-117.
Giménez-Morera, A., Sinoga, J. R., & Cerdà, A. (2010). The impact of cotton geotextiles on soil and water losses from Mediterranean rainfed agricultural land. *Land Degradation & Development*, *21*(2), 210-217.
Goldshleger, N., Ben-Dor, E., Lugassi, R., & Eshel, G. (2010). Soil degradation monitoring by remote sensing: examples with three degradation processes. *Soil Science Society of America Journal*, *74*(5), 1433-1445.
González-Ubierna, S., Jorge-Mardomingo, I., Carrero-González, B., de la Cruz, M. T., & Casermeiro, M. Á. (2012). Soil organic matter evolution after the application of high doses of organic amendments in a Mediterranean calcareous soil. *Journal of Soils and Sediments*, *12*, 1257-1268.
Guillot, E., Bertrand, I., Rumpel, C., Gomez, C., Arnal, D., Abadie, J., & Hinsinger, P. (2021). Spatial heterogeneity of soil quality within a Mediterranean alley cropping agroforestry system: Comparison with a monocropping system. *European Journal of Soil Biology*, *105*, 103330.
Higgins, S., Kadziuliene, Z., Paz, A., Mason, E., Vervuurt, W., Astover, A., ... & Wall, D. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 2.13 Stocktake study and recommendations for harmonizing methodologies for fertilization guidelines. EJP Soil.Phillips, A., Marandola, D., O'Sullivan, L., Gascuel, C., Jacob, M., Orman, T., ... & Chenu, C. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 8.1 Methodology for policy stakeholder survey/interviews. EJP Soil.
Holland, J. M. (2004). The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. *Agriculture, ecosystems & environment*, *103*(1), 1-25.
Jacobs, A., Don, A., Sanches, B., Gascuel, C., O'Sullivan, L., Berggreen, L. C., ... & Kuikman, P. J. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 8.4 Mapping policy stakeholders up to EU level across EJP SOIL Partner Countries. EJP Soil.
Jacobsen, S. E., Jensen, C. R., & Liu, F. (2012). Improving crop production in the arid Mediterranean climate. *Field Crops Research*, *128*, 34-47.
Jez, J. M., Topp, C. N., Schlautman, B., Bartel, C., Diaz-Garcia, L., Fei, S., ... & Raman, D. R. (2021). Perennial groundcovers: an emerging technology for soil conservation and the sustainable intensification of agriculture. *Emerging Topics in Life Sciences*, *5*(2), 337-347.
Jie, C., Jing-Zhang, C., Man-Zhi, T., & Zi-tong, G. (2002). Soil degradation: a global problem endangering sustainable development. Journal of Geographical Sciences, 12, 243-252.
Jiménez, M. N., Pinto, J. R., Ripoll, M. A., Sánchez-Miranda, A., & Navarro, F. B. (2017). Impact of straw and rock-fragment mulches on soil moisture and early growth of holm oaks in a semiarid area. *Catena*, *152*, 198-206.
Karlen, D. L., & Rice, C. W. (2015). Soil degradation: Will humankind ever learn?. Sustainability, 7(9), 12490-12501.
Kayikcioglu, H. H., Duman, İ., Asciogul, T. K., Bozokalfa, M. K., & Elmacı, Ö. L. (2020). Effects of tomato-based rotations with diversified pre-planting on soil health in the Mediterranean soils of Western Turkey. *Agriculture, Ecosystems & Environment*, *299*, 106986.
Keesstra, S. D., Jacob, M., Maenhout, P., Verzandvoort, S. J. E., Ruysschaert, G., Huber, S., ... & de Haan, J. J. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 2.5 Report on identified regional, national and European aspirations on soil services and soil functions. EJP Soil.

Keesstra, S. D., Munkholm, L., Zechmeister-Boltenstern, S., Taghizadeh-Toosi, A., Knadel, M., Nørgaard, T., ... & Vervuurt, W. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable D2. 6 Set of reports on State of knowledge in agricultural soil management.

Keesstra, S. D., Rodrigo-Comino, J., Novara, A., Giménez-Morera, A., Pulido, M., Di Prima, S., & Cerdà, A. (2019). Straw mulch as a sustainable solution to decrease runoff and erosion in glyphosate-treated clementine plantations in Eastern Spain. An assessment using rainfall simulation experiments. Catena, 174, 95-103.

Keesstra, S. D., Rodrigo-Comino, J., Novara, A., Giménez-Morera, A., Pulido, M., Di Prima, S., & Cerdà, A. (2019). Straw mulch as a sustainable solution to decrease runoff and erosion in glyphosate-treated clementine plantations in Eastern Spain. An assessment using rainfall simulation experiments. *Catena*, *174*, 95-103

Keesstra, S. D., Visser, S. M., Faber, J. H., Kuikman, P. J., & van Egmond, F. M. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 2.4 Roadmap for the European Joint Programme SOIL Due date of deliverable: M14.

Keesstra, S., Pereira, P., Novara, A., Brevik, E. C., Azorin-Molina, C., Parras-Alcántara, L., ... & Cerdà, A. (2016). Effects of soil management techniques on soil water erosion in apricot orchards. *Science of the Total Environment*, *551*, 357-366.

Kernecker, M., Knierim, A., Wurbs, A., Kraus, T., & Borges, F. (2020). Experience versus expectation: Farmers' perceptions of smart farming technologies for cropping systems across Europe. *Precision Agriculture*, *21*, 34-50. Quinkenstein, A., Woellecke, J., Böhm, C., Grünewald, H., Freese, D., Schneider, B. U., & Hüttl, R. F. (2009). Ecological benefits of the alley cropping agroforestry system in sensitive regions of Europe. *Environmental science & policy*, *12*(8), 1112-1121.

Klages, S., Heidecke, C., Osterburg, B., Bailey, J., Calciu, I., Casey, C., ... & Velthof, G. (2020). Nitrogen surplus—a unified indicator for water pollution in Europe?. *Water*, *12*(4), 1197.

Kosmas, C., Moustakas, N., Danalatos, N. G., & Yassoglou, N. (1994). The effect of rock fragments on wheat biomass production under highly variable moisture conditions in Mediterranean environments. *Catena*, *23*(1-2), 191-198.

Lagomarsino, A., Grego, S., Marhan, S., Moscatelli, M. C., & Kandeler, E. (2009). Soil management modifies micro-scale abundance and function of soil microorganisms in a Mediterranean ecosystem. *European Journal of Soil Science*, *60*(1), 2-12.

Larney, F. J., & Angers, D. A. (2012). The role of organic amendments in soil reclamation: A review. *Canadian Journal of Soil Science*, *92*(1), 19-38.

Lasanta, T., Sánchez-Navarrete, P., Medrano-Moreno, L. M., Khorchani, M., & Nadal-Romero, E. (2020). Soil quality and soil organic carbon storage in abandoned agricultural lands: Effects of revegetation processes in a Mediterranean mid-mountain area. *Land Degradation & Development*, *31*(18), 2830-2845.

Latati, M., Aouiche, A., Tellah, S., Laribi, A., Benlahrech, S., Kaci, G., ... & Ounane, S. M. (2017). Intercropping maize and common bean enhances microbial carbon and nitrogen availability in low phosphorus soil under Mediterranean conditions. *European Journal of Soil Biology*, *80*, 9-18.

Lizaga, I., Gaspar, L., Latorre, B., & Navas, A. (2020). Variations in transport of suspended sediment and associated elements induced by rainfall and agricultural cycle in a Mediterranean agroforestry catchment. *Journal of Environmental Management*, *272*, 111020.

López-Fando, C., & Bello, A. (1995). Variability in soil nematode populations due to tillage and crop rotation in semi-arid Mediterranean agrosystems. *Soil and Tillage Research*, *36*(1-2), 59-72.

López-Garrido, R., Madejón, E., León-Camacho, M., Girón, I., Moreno, F., & Murillo, J. M. (2014). Reduced tillage as an alternative to no-tillage under Mediterranean conditions: A case study. *Soil and tillage Research*, *140*, 40-47.u

López-Vicente, M., Calvo-Seas, E., Álvarez, S., & Cerdà, A. (2020). Effectiveness of cover crops to reduce loss of soil organic matter in a rainfed vineyard. *Land*, *9*(7), 230.

López-Bellido, L., Fuentes, M., Castillo, J. E., López-Garrido, F. J., & Fernández, E. J. (1996). Long-term tillage, crop rotation, and nitrogen fertilizer effects on wheat yield under rainfed Mediterranean conditions. *Agronomy Journal*, *88*(5), 783-791.

Lovrić, M., Rois-Díaz, M., den Herder, M., Pisanelli, A., Lovrić, N., & Burgess, P. J. (2018). Driving forces for agroforestry uptake in Mediterranean Europe: application of the analytic network process. *Agroforestry Systems*, *92*, 863-876.

Lovrić, M., Rois-Díaz, M., den Herder, M., Pisanelli, A., Lovrić, N., & Burgess, P. J. (2018). Driving forces for agroforestry uptake in Mediterranean Europe: application of the analytic network process. *Agroforestry Systems*, *92*, 863-876.

Mangalassery, S., Mooney, S. J., Sparkes, D. L., Fraser, W. T., & Sjögersten, S. (2015). Impacts of zero tillage on soil enzyme activities, microbial characteristics and organic matter functional chemistry in temperate soils. *European Journal of Soil Biology*, *68*, 9-17.

Marchetti, A., Piccini, C., Francaviglia, R., & Mabit, L. (2012). Spatial distribution of soil organic matter using geostatistics: A key indicator to assess soil degradation status in central Italy. Pedosphere, 22(2), 230-242.

Marín-Martínez, A., Sanz-Cobeña, A., Bustamante, M. A., Agulló, E., & Paredes, C. (2021). Effect of organic amendment addition on soil properties, greenhouse gas emissions and grape yield in semi-arid vineyard agroecosystems. *Agronomy*, *11*(8), 1477.

Marques, M. J., Bienes, R., Cuadrado, J., Ruiz-Colmenero, M., Barbero-Sierra, C., & Velasco, A. (2015). Analysing perceptions attitudes and responses of winegrowers about sustainable land management in Central Spain. *Land Degradation & Development*, *26*(5), 458-467.

Martí, P., & García-Mayor, C. (2020). The huerta agricultural landscape in the spanish Mediterranean arc: One landscape, two perspectives, three specific huertas. *Land*, *9*(11), 460.

Martin-Gorriz, B., Zabala, J. A., Sánchez-Navarro, V., Gallego-Elvira, B., Martínez-García, V., Alcon, F., & Maestre-Valero, J. F. (2022). Intercropping Practices in Mediterranean Mandarin Orchards from an Environmental and Economic Perspective. *Agriculture*, *12*(5), 574.

Martínez, E., Fuentes, J. P., Silva, P., Valle, S., & Acevedo, E. (2008). Soil physical properties and wheat root growth as affected by no-tillage and conventional tillage systems in a Mediterranean environment of Chile. *Soil and Tillage Research*, *99*(2), 232-244.

Martinho, V. J. P. D. (2019). Best management practices from agricultural economics: Mitigating air, soil and water pollution. *Science of the total environment*, *688*, 346-360.

Mas, M. T., & Verdú, A. M. (2003). Tillage system effects on weed communities in a 4-year crop rotation under Mediterranean dryland conditions. *Soil and Tillage Research*, *74*(1), 15-24.

Mazzoncini, M., Antichi, D., Di Bene, C., Risaliti, R., Petri, M., & Bonari, E. (2016). Soil carbon and nitrogen changes after 28 years of no-tillage management under Mediterranean conditions. *European Journal of Agronomy*, *77*, 156-165.

Mercenaro, L., Nieddu, G., Pulina, P., & Porqueddu, C. (2014). Sustainable management of an intercropped Mediterranean vineyard. *Agriculture, Ecosystems & Environment*, *192*, 95-104.

Montemurro, F., Persiani, A., & Diacono, M. (2020). Cover crop as living mulch: effects on energy flows in Mediterranean organic cropping systems. *Agronomy*, *10*(5), 667.

Monti, M., Badagliacca, G., Romeo, M., & Gelsomino, A. (2021). No-Till and solid digestate amendment selectively affect the potential denitrification activity in two Mediterranean orchard soils. *Soil Systems*, *5*(2), 31.

Morever, there will be a positive impact that will contribute to reduce the land the soil losses.

Mosquera-Losada, M. R., Rodríguez-Rigueiro, F. J., Santiago-Freijanes, J. J., Rigueiro-Rodríguez, A., Silva-Losada, P., Pantera, A., ... & Ferreiro-Domínguez, N. (2022). European agroforestry policy promotion in arable Mediterranean areas. *Land Use Policy*, *120*, 106274.

Moukanni, N., Brewer, K. M., Gaudin, A., & O'Geen, A. T. (2022). Optimizing carbon sequestration through cover cropping in Mediterranean Agroecosystems: Synthesis of Mechanisms and Implications for Management. *Frontiers in Agronomy*, *4*, 26.

Moussa-Machraoui, S. B., Errouissi, F., Ben-Hammouda, M., & Nouira, S. (2010). Comparative effects of conventional and no-tillage management on some soil properties under Mediterranean semi-arid conditions in northwestern Tunisia. *Soil and Tillage Research*, *106*(2), 247-253.

Nachshon, U. (2020). Soil degradation processes: It's time to take our head out of the sand. *Geosciences*, *11*(1), 2.

Nadal-Romero, E., Cammeraat, E., Pérez-Cardiel, E., & Lasanta, T. (2016). How do soil organic carbon stocks change after cropland abandonment in Mediterranean humid mountain areas?. *Science of the Total Environment*, *566*, 741-752.

Novara, A., Catania, V., Tolone, M., Gristina, L., Laudicina, V. A., & Quatrini, P. (2020). Cover crop impact on soil organic carbon, nitrogen dynamics and microbial diversity in a Mediterranean semiarid vineyard. *Sustainability*, *12*(8), 3256.

Novara, A., Cerda, A., Barone, E., & Gristina, L. (2021). Cover crop management and water conservation in vineyard and olive orchards. *Soil and Tillage Research*, *208*, 104896.

Novara, A., Gristina, L., Sala, G., Galati, A., Crescimanno, M., Cerdà, A., ... & La Mantia, T. (2017). Agricultural land abandonment in Mediterranean environment provides ecosystem services via soil carbon sequestration. *Science of the Total Environment*, *576*, 420-429.

Novara, A., Gristina, L., Sala, G., Galati, A., Crescimanno, M., Cerdà, A., ... & La Mantia, T. (2017). Agricultural land abandonment in Mediterranean environment provides ecosystem services via soil carbon sequestration. *Science of the Total Environment*, *576*, 420-42

Novara, A., Minacapilli, M., Santoro, A., Rodrigo-Comino, J., Carrubba, A., Sarno, M., ... & Gristina, L. (2019). Real cover crops contribution to soil organic carbon sequestration in sloping vineyard. *Science of the Total Environment*, *652*, 300-306.

Novara, A., Pulido, M., Rodrigo-Comino, J., Di Prima, S., Smith, P., Gristina, L., ... & Keesstra, S. (2019). Long-term organic farming on a citrus plantation results in soil organic carbon recovery. *Cuadernos de Investigación Geográfica*, *45*(1), 271-286.

Oliveira, M., Castro, C., Coutinho, J., & Trindade, H. (2019). N supply and pre-cropping benefits to triticale from three legumes in rainfed and irrigated Mediterranean crop rotations. *Field Crops Research*, *237*, 32-42.

Pastorelli, R., Vignozzi, N., Landi, S., Piccolo, R., Orsini, R., Seddaiu, G., ... & Pagliai, M. (2013). Consequences on macroporosity and bacterial diversity of adopting a no-tillage farming system in a clayish soil of Central Italy. *Soil Biology and Biochemistry*, *66*, 78-93.

Pavlu, L., Sobocka, L., Boruvka, L., Penizek, V., Adamczyk, B., Baumgarten, A., ... & Vervuurt, W. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 2.2 Stocktaking on soil quality indicators and associated decision support tools, including ICT tools. EJP Soil.

Paz, A., Vervuurt, W., de Haan, J., Spiegel, H., Carranca, C., Miloczki, J., ... & Vicente, C. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 2.1 Synthesis of the impacts of sustainable soil management practices in Europe. European Joint Programme Soil.

Peralta, G., Alvarez, C. R., & Taboada, M. A. (2021). Soil compaction alleviation by deep non-inversion tillage and crop yield responses in no tilled soils of the Pampas region of Argentina. A meta-analysis. *Soil and Tillage Research*, *211*, 105022.

Picariello, E., Pucci, L., Carotenuto, M., Libralato, G., Lofrano, G., & Baldantoni, D. (2020). Compost and sewage sludge for the improvement of soil chemical and biological quality of Mediterranean agroecosystems. *Sustainability*, *13*(1), 26.

Piñar Fuentes, J. C., Leiva, F., Cano-Ortiz, A., Musarella, C. M., Quinto-Canas, R., Pinto-Gomes, C. J., & Cano, E. (2021). Impact of grass cover management with herbicides on biodiversity, soil cover and humidity in olive groves in the Southern Iberian. Agronomy, 11(3), 412.

Poesen, J., & Bunte, K. (1996). The effects of rock fragments on desertification processes in Mediterranean environments. *Mediterranean desertification and land use.*, 247-269.

Porqueddu, C., Re, G. A., Sanna, F., Piluzza, G., Sulas, L., Franca, A., & Bullitta, S. (2016). Exploitation of annual and perennial herbaceous species for the rehabilitation of a sand quarry in a Mediterranean environment. *Land Degradation & Development*, *27*(2), 346-356.

Powlson, D. S., Bhogal, A., Chambers, B. J., Coleman, K., Macdonald, A. J., Goulding, K. W. T., & Whitmore, A. P. (2012). The potential to increase soil carbon stocks through reduced tillage or organic material additions in England and Wales: a case study. *Agriculture, Ecosystems & Environment*, *146*(1), 23-33.

Powlson, D. S., Riche, A. B., Coleman, K., Glendining, M. J., & Whitmore, A. P. (2008). Carbon sequestration in European soils through straw incorporation: limitations and alternatives. *Waste Management*, *28*(4), 741-746.

Prosdocimi, M., Jordán, A., Tarolli, P., Keesstra, S., Novara, A., & Cerdà, A. (2016). The immediate effectiveness of barley straw mulch in reducing soil erodibility and surface runoff generation in Mediterranean vineyards. *Science of the Total Environment*, *547*, 323-330.

Querné, A., Battie-laclau, P., Dufour, L., Wery, J., & Dupraz, C. (2017). Effects of walnut trees on biological nitrogen fixation and yield of intercropped alfalfa in a Mediterranean agroforestry system. *European Journal of Agronomy*, *84*, 35-46.

Raclot, D., Le Bissonnais, Y., Louchart, X., Andrieux, P., Moussa, R., & Voltz, M. (2009). Soil tillage and scale effects on erosion from fields to catchment in a Mediterranean vineyard area. *Agriculture, ecosystems & environment*, *134*(3-4), 201-210.

Rasmussen, K. J. (1999). Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review. *Soil and Tillage Research*, *53*(1), 3-14.

Repullo-Ruiberriz de Torres, M. A., Moreno-García, M., Ordóñez-Fernández, R., Rodríguez-Lizana, A., Carceles Rodriguez, B., García-Tejero, I. F., ... & Carbonell-Bojollo, R. M. (2021). Cover crop contributions to improve the soil nitrogen and carbon sequestration in almond orchards (SW Spain). *Agronomy*, *11*(2), 387.

Restuccia, A., Scavo, A., Lombardo, S., Pandino, G., Fontanazza, S., Anastasi, U., ... & Mauromicale, G. (2020). Long-term effect of cover crops on species abundance and diversity of weed flora. *Plants*, *9*(11), 1506.

Ripoche, A., Rellier, J. P., Martin-Clouaire, R., Paré, N., Biarnès, A., & Gary, C. (2011). Modelling adaptive management of intercropping in vineyards to satisfy agronomic and environmental performances under Mediterranean climate. *Environmental Modelling & Software*, *26*(12), 1467-1480.

Rodrigo-Comino, J., Martínez-Hernández, C., Iserloh, T., & Cerda, A. (2018). Contrasted impact of land abandonment on soil erosion in Mediterranean agriculture fields. *Pedosphere*, *28*(4), 617-631.

Rodrigo-Comino, J., García-Díaz, A., Brevik, E. C., Keestra, S. D., Pereira, P., Novara, A., ... & Cerdà, A. (2017). Role of rock fragment cover on runoff generation and sediment yield in tilled vineyards. *European Journal of Soil Science*, *68*(6), 864-872.

Rodrigues, L., Fohrafellner, J., Hardy, B., Huyghebaert, B., Leifeld, J., Lesschen, J. P., ... & Lazdiņš, A. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 2.3 Synthesis on estimates of achievable soil carbon sequestration on agricutural land across Europe. EJP Soil.
Rodrigues, M. Â., & Arrobas, M. (2020). Cover cropping for increasing fruit production and farming sustainability. In *Fruit Crops* (pp. 279-295). Elsevier.
Romanos, D., Nemer, N., Khairallah, Y., & Abi Saab, M. T. (2019). Assessing the quality of sewage sludge as an agricultural soil amendment in Mediterranean habitats. *International Journal of Recycling of Organic Waste in Agriculture*, *8*, 377-383.
Romero-Díaz, A., Ruiz-Sinoga, J. D., Robledano-Aymerich, F., Brevik, E. C., & Cerdà, A. (2017). Ecosystem responses to land abandonment in Western Mediterranean Mountains. *Catena*, *149*, 824-835.
Ronchi, S., Salata, S., Arcidiacono, A., Piroli, E., & Montanarella, L. (2019). Policy instruments for soil protection among the EU member states: A comparative analysis. *Land Use Policy*, *82*, 763-780.
Roose, E., Bellefontaine, R., & Visser, M. (2011). Six rules for the rapid restoration of degraded lands: Synthesis of 17 case studies in tropical and Mediterranean climates. *Science et changements planétaires/Sécheresse*, *22*(2), 86-96.
Ros, M., Hernandez, M. T., & García, C. (2003). Soil microbial activity after restoration of a semiarid soil by organic amendments. *Soil Biology and Biochemistry*, *35*(3), 463-469.
Ruisi, P., Giambalvo, D., Saia, S., Di Miceli, G., Frenda, A. S., Plaia, A., & Amato, G. (2014). Conservation tillage in a semiarid Mediterranean environment: results of 20 years of research. *Italian Journal of Agronomy*, *9*(1), 1-7.
Ruiz-Sinoga, J. D., & Diaz, A. R. (2010). Soil degradation factors along a Mediterranean pluviometric gradient in Southern Spain. *Geomorphology*, *118*(3-4), 359-368.
Ruysschaert, G., & Jacob, M. (2021). TOWARDS CLIMATE-SMART SUSTAINABLE MANAGEMENT OF AGRICULTURAL SOILS IN FLANDERS: Part I: EJP SOIL survey on current policy ambitions and future soil aspirational goals.
Ruysschaert, G., De Boever, M., Jacob, M., Maenhout, P., & D'Hose, T. (2021). Towards climate-smart sustainable management of agricultural soils in Flanders: Part II: EJP SOIL survey on current research knowledge and stakeholder views on knowledge needs, barriers and opportunities for the knowledge system.
Sadiki, A., Faleh, A., Navas, A., & Bouhlassa, S. (2009). Using magnetic susceptibility to assess soil degradation in the Eastern Rif, Morocco. *Earth Surface Processes and Landforms*, *34*(15), 2057-2069.
Salama, H. S., Nawar, A. I., & Khalil, H. E. (2022). Intercropping pattern and N fertilizer schedule affect the performance of additively intercropped maize and forage cowpea in the Mediterranean region. *Agronomy*, *12*(1), 107.
Salata, S., & Thompson Couch, V. (2022). Monitoring Soil Degradation Processes for Ecological Compensation in the Izmir Institute of Technology Campus (Turkey). *Eng*, *3*(3), 325.
Salvati, L., Bajocco, S., Ceccarelli, T., Zitti, M., & Perini, L. (2011). Towards a process-based evaluation of land vulnerability to soil degradation in Italy. *Ecological Indicators*, *11*(5), 1216-1227.
Salvati, L., Kosmas, C., Kairis, O., Karavitis, C., Acikalin, S., Belgacem, A., ... & De Vente, J. (2015). Unveiling soil degradation and desertification risk in the Mediterranean basin: a data mining analysis of the relationships between biophysical and socioeconomic factors in agro-forest landscapes. *Journal of Environmental Planning and Management*, *58*(10), 1789-1803.
Šarapatka, B., & Bednář, M. (2015). Assessment of potential soil degradation on agricultural land in the Czech Republic. Journal of Environmental Quality, 44(1), 154-161.
Sastre, B., Barbero-Sierra, C., Bienes, R., Marques, M. J., & García-Díaz, A. (2017). Soil loss in an olive grove in Central Spain under cover crops and tillage treatments, and farmer perceptions. *Journal of Soils and Sediments*, *17*, 873-888.
Scavo, A., Restuccia, A., Abbate, C., Lombardo, S., Fontanazza, S., Pandino, G., ... & Mauromicale, G. (2021). Trifolium subterraneum cover cropping enhances soil fertility and weed seedbank dynamics in a Mediterranean apricot orchard. *Agronomy for Sustainable Development*, *41*, 1-16.
Scavo, A., Restuccia, A., Lombardo, S., Fontanazza, S., Abbate, C., Pandino, G., ... & Mauromicale, G. (2020). Improving soil health, weed management and nitrogen dynamics by Trifolium subterraneum cover cropping. *Agronomy for Sustainable Development*, *40*, 1-12.
Scotti, R., Bonanomi, G., Scelza, R., Zoina, A., & Rao, M. A. (2015). Organic amendments as sustainable tool to recovery fertility in intensive agricultural systems. *Journal of soil science and plant nutrition*, *15*(2), 333-352.
Sekucia, F., Dlapa, P., Kollár, J., Cerdá, A., Hrabovský, A., & Svobodová, L. (2020). Land-use impact on porosity and water retention of soils rich in rock fragments. *Catena*, *195*, 104807.
Serbaji, M. M., Bouaziz, M., & Weslati, O. (2023). Soil Water erosion modeling in Tunisia using RUSLE and GIS integrated approaches and Geospatial Data. *Land*, *12*(3), 548
Shao, Q., Gu, W., Dai, Q. Y., Makoto, S., & Liu, Y. (2014). Effectiveness of geotextile mulches for slope restoration in semi-arid northern China. *Catena*, *116*, 1-9.

Siles, J. A., Rachid, C. T., Sampedro, I., Garcia-Romera, I., & Tiedje, J. M. (2014). Microbial diversity of a Mediterranean soil and its changes after biotransformed dry olive residue amendment. *PLoS One*, *9*(7), e103035.

Smith, P. (2004). Carbon sequestration in croplands: the potential in Europe and the global context. *European journal of agronomy*, *20*(3), 229-236.

Soussana, J. F., Arias-Navarro, C., Tanikawa, S., & Kuikman, P. J. (2021). Circasa; coordination of international Research cooperation and Soil Carbon sequestration in Agriculture. Project Repository Journal, 8(January), 94-97.

Stagnari, F., Galieni, A., Speca, S., Cafiero, G., & Pisante, M. (2014). Effects of straw mulch on growth and yield of durum wheat during transition to conservation agriculture in Mediterranean environment. *Field Crops Research*, *167*, 51-63.

Steinmann, T., Welp, G., Wolf, A., Holbeck, B., Große-Rüschkamp, T., & Amelung, W. (2016). Repeated monitoring of organic carbon stocks after eight years reveals carbon losses from intensively managed agricultural soils in Western Germany. *Journal of Plant Nutrition and Soil Science*, *179*(3), 355-366.

Stolte, J., Tesfai, M., Oygarden, L., Kvaerno, S., Keizer, J., Verheijen, F., ... & Hessel, R. (2016). Soil threats in Europe: status, methods, drivers and effects on ecosystem services: deliverable 2.1 RECARE project. European Commission DG Joint Research Centre. 206 pages.

Tairi, A., Elmouden, A., Bouchaou, L., & Aboulouafa, M. (2021). Mapping soil erosion–prone sites through GIS and remote sensing for the Tifnout Askaoun watershed, southern Morocco. *Arabian Journal of Geosciences*, *14*(9), 811.

Tejada, M., & Benítez, C. (2014). Effects of crushed maize straw residues on soil biological properties and soil restoration. *Land Degradation & Development*, *25*(5), 501-509.

Temani, F., Bouaziz, A., Daoui, K., Wery, J., & Barkaoui, K. (2021). Olive agroforestry can improve land productivity even under low water availability in the South Mediterranean. *Agriculture, Ecosystems & Environment*, *307*, 107234.

Tóth, G., Hermann, T., Szatmári, G., & Pásztor, L. (2016). Maps of heavy metals in the soils of the European Union and proposed priority areas for detailed assessment. *Science of the total environment*, *565*, 1054-1062.

Tyohemba, R. L., Pillay, L., & Humphries, M. S. (2021). Bioaccumulation of current-use herbicides in fish from a global biodiversity hotspot: Lake St Lucia, South Africa. Chemosphere, 284, 131407.

van Egmond, F. M., Fantappie, M., Batjes, N. H., Brus, D. J., Bulens, J. D., Kempen, B., ... & Heuvelink, G. B. M. (2021). Towards climate-smart sustainable management of agricultural soils: Deliverable 6.1 Report on harmonized procedures for creation of databases and maps. EJP Soil.

Vazquez, E., Benito, M., Navas, M., Espejo, R., Diaz-Pines, E., & Teutscherova, N. (2019). The interactive effect of no-tillage and liming on gross N transformation rates during the summer fallow in an acid Mediterranean soil. *Soil and Tillage Research*, *194*, 104297.

Vermeulen, S., Bossio, D., Lehmann, J., Luu, P., Paustian, K., Webb, C., ... & Warnken, M. (2019). A global agenda for collective action on soil carbon. Nature Sustainability, 2(1), 2-4.

Virto, I., Imaz, M. J., Fernández-Ugalde, O., Gartzia-Bengoetxea, N., Enrique, A., & Bescansa, P. (2014). Soil degradation and soil quality in Western Europe: Current situation and future perspectives. Sustainability, 7(1), 313-365.

Visser, S., Keesstra, S., Ní Choncubhair, Ó., Mulder, T., Costantini, E., Sousanna, J. F., ... & Borchard, N. (2020). Roadmap for the European Joint Program SOIL: towards climate-smart sustainable management of agricultural soils. TERRAenVISION 2019, Barcelona, Spain| 2–7 September 2019.

Volaire, F., Norton, M. R., & Lelièvre, F. (2009). Summer drought survival strategies and sustainability of perennial temperate forage grasses in Mediterranean areas. *Crop Science*, *49*(6), 2386-2392.

Walling, E., & Vaneeckhaute, C. (2020). Greenhouse gas emissions from inorganic and organic fertilizer production and use: A review of emission factors and their variability. *Journal of Environmental Management*, *276*, 111211.

Wang, X. B., Cai, D. X., Hoogmoed, W. B., Oenema, O., & Perdok, U. D. (2007). Developments in conservation tillage in rainfed regions of North China. *Soil and Tillage Research*, *93*(2), 239-250.

Wijdenes, D. O., Poesen, J., Vandekerckhove, L., & De Luna, E. (1997). Chiselling effects on the vertical distribution of rock fragments in the tilled layer of a Mediterranean soil. *Soil and Tillage Research*, *44*(1-2), 55-66.

Wriedt, G., Van der Velde, M., Aloe, A., & Bouraoui, F. (2009). Estimating irrigation water requirements in Europe. *Journal of Hydrology*, *373*(3-4), 527-544.

Wynants, M., Kelly, C., Mtei, K., Munishi, L., Patrick, A., Rabinovich, A., ... & Ndakidemi, P. (2019). Drivers of increased soil erosion in East Africa’s agro-pastoral systems: changing interactions between the social, economic and natural domains. Regional Environmental Change, 19, 1909-1921.

Yilmaz, Ş., Atak, M., & Erayman, M. (2008). Identification of advantages of maize-legume intercropping over solitary cropping through competition indices in the East Mediterranean Region. *Turkish Journal of Agriculture and Forestry*, *32*(2), 111-119.

Zaimes, G. N., Tardio, G., Iakovoglou, V., Gimenez, M., Garcia-Rodriguez, J. L., & Sangalli, P. (2019). New tools and approaches to promote soil and water bioengineering in the Mediterranean. *Science of the Total Environment*, *693*, 133677.

Zhang, Y., Zhang, M., Niu, J., Li, H., Xiao, R., Zheng, H., & Bech, J. (2016). Rock fragments and soil hydrological processes: significance and progress. *Catena*, *147*, 153-166.