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CARBON 4 SOIL QUALITY

Guidelines for carbon farming techniques

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1 INTRODUCTION

Carbon Farming refers to agroecosystem management practices aimed at mitigating the effects of emissions generated by human activities. This involves managing all carbon pools involved in the process, including those stored in soil, materials used, and vegetation. Mitigation can be achieved through three primary approaches:

- Carbon removal from the atmosphere, achieved by long-term sequestering carbon in soils and biomass.
- Avoiding emissions of already sequestered carbon.
- Reducing greenhouse gas emissions, particularly CO_2 and CH_4, associated with agricultural operations.

Both the FAO (FAO and ITPS, 2021) and the European Union (McDonald et al., 2021) identify five main subcategories for classifying carbon farming practices:

- Peatland rewetting and restoration,
- Establishment and maintenance of agroforestry systems,
- Maintenance and enhancement of soil organic carbon (SOC) on mineral soils,
- Livestock and manure management,
- Nutrient management on croplands and grasslands.

In the framework of the Carbon 4 Soil project, the main goal is to increase organic carbon reserves in Mediterranean soils. This approach serves two complementary objectives: improving soil fertility while simultaneously enhancing carbon sequestration from the atmosphere.

For this reason, the third category is the primary focus of this report. Maintaining and enhancing SOC in mineral soils is obtained via a positive balance between carbon inputs and carbon losses from soils and can be implemented in any farming system. Compared to other carbon farming techniques, estimates of its mitigation potential are significantly more uncertain. For instance, European-level estimates of mitigation potential range from 9 Mt CO_2-eq per year, as suggested by Frank et al. (2015) to as high as 70 Mt CO_2-eq per year, according to Roe et al (2021). Localized estimates for the Mediterranean region are currently unavailable. However, as highlighted by Lugato et al. (2014), southern and eastern Europe are projected to be the only regions in Europe experiencing a decline in soil carbon stocks by 2100 due to climate change, assuming current agricultural systems remain unchanged. Under these circumstances, merely maintaining the current SOC stock would represent a significant achievement for Mediterranean areas facing higher temperatures. Moreover, Roe et al. (2021) identifies soil carbon sequestration as the most effective carbon farming measure for countries like Italy and Spain.

Worth noting are the ecosystem services provided by maintaining or increasing SOC stocks. These include erosion prevention, enhanced soil fertility, improved water retention, support for soil biodiversity, and reduced soil compaction. However, potential risks may arise from practices that introduce organic materials such as biochar or sewage sludge, due to the possibility of contaminants introduction into the soil.

1.1 Objectives

The objective of this report is to compare Best Management Practices (BMPs) aimed at increasing soil organic matter content in Euro-Mediterranean countries. In addition, it analyses the associated benefits and disadvantages of these practices and evaluates their costs and geographical suitability.

BMPs are classified in the four following categories:

1. soil management techniques
2. organic additions
3. cultivation practices
4. cultivation systems

The report is structured into two main sections. The first section summarizes the key aspects across six thematic areas. The second section provides a detailed, visually oriented description of each BMP using infographics material.

2 SOIL MANAGEMENT TECHNIQUES

2.1 Organic mulch

Definition: Mulch is defined as any biodegradable material applied to the soil to prevent erosion and water loss, inhibite weed germination, reduce soil particle splashing in fruits, therefore reducing the risk of pathogens, and modify soil temperatures. It can be either organic or inorganic, with the organic option being preferred, as it does not pose a contamination risk like polyethylene or rubber alternatives. This technique has long been used by small-scale farmers, with various parent materials employed worldwide as sources of organic mulch, including crop residues, bark, straw, sawdust, leaves, and composted animal manure (Chopra and Koul 2020; FAO and ITPS 2021).

Mitigation Potential: It is not easy to precisely determine the extent to which organic mulching contributes to the increase in SOC. As in other cases, this largely depends on the type of agriculture practiced over time and the specific pedoclimatic characteristics of the soil. Studies estimating the direct effects of organic mulch in Mediterranean areas are relatively recent. These works report that the increase in SOC is due both to the conversion of biomass input into organic matter and to a reduction in CO2emissions from the soil. The increase is particularly notable in highly intensive systems and is most evident in the top 15 cm of soil, with SOC increments of up to 45% (Gómez et al., 2022).

Associated benefits: Organic mulching not only contributes to soil carbon stocks but is also one of the most effective techniques for weed control. It achieves this by blocking light from reaching the seed bank and through the release of allelopathic substances during decomposition. Additionally, these properties aid in pest control by promoting the proliferation of beneficial microbial and insect communities. The resulting increase in biodiversity and biomass helps suppress harmful species that might otherwise attack cultivated crops (Jabran and Jabran, 2019).

By covering the soil, organic mulch slows down the decomposition of organic material, which in turn decreases soil temperature and regulates the microclimate. Like other types of soil cover, organic mulch enhances soil water retention without compromising infiltration. Its use in agricultural systems significantly improves water-use efficiency, potentially reducing evaporation by up to 35% (Goodman, 2020).

Organic mulching also enhances soil structural properties by increasing surface and aggregate stability, while improving connectivity between macropores. Finally, as the mulch decomposes, it provides essential nutrients for crop growth.

Disadvantages: Mulches with a low C:N ration, such as legumes residues, decompose rapidly and provide extra N to the soil microbial biomass which increases production of nitrous oxide (N2O). Secondly, the allelopathy induced by the organic mulch might affect also the herbaceous crops.

Costs: The costs linked to the application of this technique regard the cost of the organic mulch itself, its transportation and its application (Rodrigo-Comino et al., 2020).

Geographical suitability: Mulching can be applied in any pedoclimatic region, but it is most economically viable in areas with higher net productivity, where crop residues are less likely to be needed for purposes such as animal feed.

2.2 Conservation tillage

Definition: Conservation tillage refers to any method of soil cultivation that reduces the frequency of soil disturbance, avoids soil inversion, minimizes the disruption of soil aggregates, and ensures that at least 30% of the soil surface remains covered with crop residues (SSSA, 2008). Several methods—such as Minimum Tillage, Strip Tillage, and No-till/Direct Drilling—can be considered forms of conservation tillage, provided they meet the basic criterion of maintaining at least 30% residue cover on the soil surface.

Mitigation Potential: In warm and dry temperate Mediterranean area, the additional storage of C resulting from the conservation tillage applied for more than 6 years ranges from 0.78 to 2.0 tC /ha/year before reaching saturation levels (Vicente-Vicente et al., 2016). This sequestration potential tends to decrease over time, as soils approach a new equilibrium in soil organic matter content.

Associated benefits: Not only the stock of soil C increases but also other properties are enhanced by conservation tillage such as aggregate stability, soil water infiltration capacity and soil resilience to temperature and moisture fluctuations (Almagro et al., 2017).

Disadvantages: Even though a precise evaluation of the effects of this practice do not exist since it varies a lot depending on the crop, the economic and pedoclimatic factors, generally yields tend to be reduced compared to conventional tillage: even though this is not always the case, such as fruit orchards, where minimum tillage can enhance water conservation. Soil might me contaminated by an excessive amount of herbicide due to weeds being not eradicated mechanically and lastly there’s an increase in soil compaction and penetration resistance. In addition, there is significant debate about the future use of glyphosate, on which many of these practices heavily rely. Its approval in the EU has been renewed for 10 years, until December 2033.

Costs: Some farmers might encounter the barrier of equipment when starting applying conservation tillage (Dal Ferro et al., 2020), but for those that do not have to buy any tilling machines the cost are reduced (-12%) compared to conventional tillage (Bowman et al., 2020).

Geographical suitability: Conservation tillage has already been widely adopted in the Mediterranean basin, and its cost-effectiveness also depends on the other measures implemented alongside it. (Madejón et al., 2009; Ruisi et al., 2014).

2.3 No-tillage

Definition: No-tillage is one of the pillar of conservation agriculture. Field crops and trees in orchards are planted without any tillage to prepare the seedbed, except a narrow strip of maximum 5 cm for seed placement to ensure adequate seed-soil contact. The soil surface is covered by residues of previous crop and/or mulch or sod. This soil cover is key to water conservation. Weed control is achieved through herbicides and fertilizers operation are coupled with the seeding ones (Baker and Saxton, 2007).

Mitigation Potential: The debate regarding the mitigation potential of no-tillage practices remains ongoing. In some areas of the Mediterranean basin, the adoption of no-tillage for at least three years led to an 11.4% increase in SOC stocks, with a sequestration rate of 0.44 tC/ha/year (Aguilera et al., 2013).

Associated benefits: Thanks to the permanent soil cover, soil is less affected by erosion caused by wind and water. The soil cover is responsible also for the increased soil moisture and decreased water loss, which enhance soil biodiversity, with a 37% increase in biomass (FAO and ITPS, 2021).

Disadvantages: No till has been widely associated with herbicide resistance of weeds and their persistence in soil (Van Deynzeet al., 2022). When a resistance to the herbicide appears the composition of the flora may change in favour of herbicide resistant species, such as the case observed in steep olive orchards in Spain countryside.Entering the field with heavy machinery without proper management leads to soil compaction, which lowers soil temperature and, in turn, causes nutrient imbalances by slowing the release of nutrients from organic matter (FAO and ITPS, 2021). Response in global yield production is variable, but a reduction is likely registered (Pittelkow et al., 2015; Salem et al., 2015). Attention has to be paid on SOC MRV measures since the increase could interest only the first 20 cm of soil, leaving the deeper horizon, with higher sequestration potential, unable to store additional carbon. Additionally, no-tillage might lead to nutrient stratification and accumulation in the upper soil layers and may reduce nutrient availability for deeper roots (Souza et al. 2023).

Costs: Savings in European soils have been estimated in relation to reduced fuel consumption, lower fertilizer requirements, and decreased soil degradation, even though this changes based on soil type (reduced fuel use by 20–53 l ha^{-1}, corresponding to ~41 kg CO_2-C ha^{-1})(Soane at al., 2012).

Geographical suitability: No-till is a practice already widely adopted in some part of the world Despite being a technique widely used both in dry areas and in very humid ones, adoption rate in Southern Europe is still very low (<10% of arable area) but more common in fruit crops(Soane et al., 2012).

2.4 Strip Tillage, Precision Tillage, Zone Tillage

Definition: Strip Tillage, Precision Tillage, Zone Tillage fall under Conservation Tillage and aim to minimize soil disturbance by limiting tillage to the crop row, leaving the rest of the soil undisturbed and covered with residues. At the same time, they seek to maximize yield by mechanically preparing a seedbed optimized for soil conditions and the microclimate, promoting germination and seedling establishment. (FAO and ITPS, 2021; Lange and Peake, 2020).

Mitigation Potential: There are no precise estimates of the potential for carbon sequestration by these precision tillage techniques in the Mediterranean area.

Associated benefits: Soil properties improve in the undisturbed zones, where aggregate stability, temperature regulation, fungal and bacterial biomass, and water storage capacity are enhanced. Additionally, the tilled strips exhibit lower bulk density, which facilitates better root penetration. Compared to conventional and no-tillage systems, increased crop yields have also been reported. Greenhouse gas emissions are lower compared to conventional tillage due to labor reduction (FAO and ITPS, 2021; Douet al., 2024).

Disadvantages: During the initial years of transition from conventional tillage, some yield reduction may occur due to limited experience and insufficient expertise with the technique (FAO and ITPS, 2021). As stated for no-tillage and conservation tillage, herbicide use increases.

Costs: Reduced costs are registered with respect to conventional tillage (Schimmelpfennig, 2018).

Geographical suitability: There are no restrictions on the use of this technique in the Mediterranean basin, with numerous areas where it is systematically applied (Benincasa et al., 2017).

3 Organic additions

3.1 Manure

Definition: Manure is organic matter originating from animal's excreta, such as faeces and urine, but also containing plant material (often straw) which is used for animal bedding. It can be found in liquid, slurry or solid form and originates from poultry, cows, sheep, horses and all other livestock animals.

Mitigation Potential: it varies according to manure type, doses, time of application and parallel agricultural practices. Estimates for the first 30 cm of soil in Mediterranean area reports an increase of 46% in SOC stock (Garcia-Pausas et al., 2017) while a meta-analysis on hot temperate areas report an increase of 5,6 tC/ha(Maillard and Angers, 2014). Typically, farmyard manure is the most effective at increasing carbon stock (Longo et al., 2021).

Associated Benefits: Manure application decreases soil bulk density, improves aggregate stability and enhances soil water retention although these positive effects are soil type and baseline dependent (FAO and ITPS, 2021). Manure contains essential elements required for plant growth that are slowly released (Teenstra et al., 2016).

Disadvantages: One of the main drawbacks of manure application is the excess phosphorus input to the soil, which can accumulate until the soil reaches a saturation point (i.e., change point) beyond which it can no longer adsorb phosphorus, leading to water pollution (Pizzeghello et al., 2011]). Additionally, nitrate leaching may occur when manure is applied at times when plants are not actively uptaking nitrogen, resulting in nitrogen losses during heavy rains. Another risk is the accumulation of trace elements, such as zinc and other heavy metals. Regarding soil acidity, the effect of manure on pH depends on both the manure's properties and specific soil conditions, with variable results. Moreover, inadequate manure management can exacerbate these environmental risks. If manure is not properly fermented, it can promote the proliferation of weeds and cause drying of the topsoil due to increased surface temperatures. In many cases, application is hindered by limited farmer awareness and insufficient on-farm infrastructure for proper storage. A common practice involves transporting manure to the field in small heaps, where it is left exposed for one to two months before being spread and incorporated. This approach often results in considerable nutrient losses and leads to localized nutrient accumulation at deposition points, causing spatial heterogeneity in soil fertility and increasing the risk of leaching and runoff.

Costs: The application of large quantities of manure involves high transport and labor costs.

Geographical suitability: No restrictions are reported for application in the Mediterranean area. However, although there are no universally applied restrictions on manure use across the Mediterranean region, it's important to recognize that local laws and environmental factors are key in shaping suitable manure management strategies. Given the region's varied climates and farming methods, customized solutions are essential to avoid ecological issues.

3.2 Crop residue incorporation

Definition: Crop residue incorporation involves the incorporation of crop residues into the soil after harvesting.

Mitigation Potential: The effectiveness of integrating crop residues into carbon sequestration varies widely depending on factors such as crop type, management practices and environmental conditions. Long-term studies have shown that annual straw incorporation has led to an increase in the soil's SOC and total nitrogen content, with relative variations generally less than 10%. One of the few long-term studies on crop residues integration (50 years) reports an increase in SOC content of approximately 12% in the tilled topsoil (0-30 cm) and 7% in the subsoil (30-60 cm) compared to the residue removal practice (Piccoli et al., 2024). Priming effects caused by residue incorporation have been observed, leading to a depletion of SOC (Camarotto et al., 2020).

Associated Benefits: Residues incorporation enhance soil structure and aggregate stability; they also reduce soil erosion by protecting soil surface and increase soil micro-biomass biodiversity. Crop residues can also act as a source of nutrients such as NPK. It is important to note that the effect of crop residue incorporation on soil properties may vary depending on factors such as soil type, climate, management practices and crop residue type (Turmel et al., 2015) Besides its benefits on soil properties, wood chipping and incorporation is becoming very popular in orchards and vineyards. due to the high costs and regulation regarding wood transport and burning.

Disadvantages: Potential increase in greenhouse gas emissions if the decomposition of waste is not managed properly. In cold climates, it can slow the emergence of seedlings. High C:N residues might immobilize N. It can also increase pest and disease pressure (Qiao et al., 2013).

In this context, some practical experiences show that breaking down crop residues doesn't always lead to positive outcomes. Thus, the use of rice straw as ground cover may elevate the leaching of dissolved organic carbon, potentially harming soil health and affecting groundwater quality (Fu et al., 2021). Furthermore, applying rice straw at a 1% weight ratio can significantly raise methylmercury concentrations in wheat (by 225%) and rice (by 20%) grains grown in mercury-contaminated paddy fields (Fu et al., 2021).

Costs: The only additional costs for the farmer are those associated with residue incorporation. Integrating crop residues into the soil can serve as an environmentally friendly and economical approach to support soil ecosystem functions, preserve soil organic carbon (SOC) levels, and enhance fertility in European agricultural soils (Lehtinen et al., 2014).

Geographical suitability: It can be applied in all Mediterranean countries without any restriction.

3.3 Compost

Definition: Compost is the biological decomposition of organic materials by microorganisms under controlled, aerobic conditions that produce a matured and stabilized organic matter naturally enriched by hydrophobic humic substances, which make it a recalcitrant biomass to further microbial degradation (Stevenson, 1994).

Mitigation Potential: The increase in carbon stock largely depends on compost quality, application rate, soil texture, and the baseline level of soil organic carbon (SOC). For this reason, it is difficult to provide a precise estimate of its mitigation potential. It is noteworthy in the Mediterranean region long-term experiments have reported large increases in SOC stocks thank to compost use ranging from 23% to 90% (Farina et al., 2018; Aguilera et al., 2013; Martín et al., 2019).

Associated Benefits: Adding compost to soil can improve soil structure, supply nutrients to plants, help to suppress pests and diseases, and potentially increase both crop yields and crop quality (Martín et al., 2019).

Disadvantages: If compost is derived from polluted residues, it can introduce heavy metals and organic pollutants into the soil. Moreover, if the composting process does not include adequate heat phases, it may pose a threat to soil microbiology. During the initial years of transitioning from mineral fertilizers to compost, a decrease in yield may be observed (FAO and ITPS, 2021)

Costs: In the case of on-farm produced compost, the production cost can vary depending on the scale of the operation, available infrastructure, and input materials. For instance, in Southern Italy, production costs have been reported to range from €10 to €30 per ton (Pergola et al., 2020). In other words, Pergola et al. (2020) indicate that generating one ton of compost resulted in CO_2-equivalent emissions between 199 and 250 kg, consumed 1500 to 2000 MJ of energy, and incurred costs ranging from 98 to 162 euros—still lower than those of commercially available green compost. If compost is purchased on the market, the cost depends on several factors, including compost quality, nutrient content, certification (e.g., organic), and regional market dynamics

Geographical suitability: No restrictions exist on the pedoclimatic requirements for compost application.

3.4 Biochar

Definition: Biochar is a form of charcoal produced through the pyrolysis of organic material. It is primarily used as a soil amendment to enhance soil fertility, but also provides long-term carbon storage. Suitable biomass feedstocks for biochar production include crop residues, garden and food waste, forestry by-products, and animal manures. However, raw materials must be free from unacceptable levels of contaminants, such as heavy metals, which are often found in sewage sludge, industrial waste, or landfill materials.

The physico-chemical properties of the resulting biochar are largely determined by both the characteristics of the raw materials and the conditions of the pyrolysis process (Pituello et al., 2015). These properties influence not only the biochar's effectiveness for specific agricultural or environmental applications but also its behaviour, mobility, and long-term fate in the environment.

Mitigation Potential: The biochar, thanks to its aromatic structure and the presence of layers similar to graphite, is able to remain stable in the soil for many years (from 100 to 4000 years). Therefore, biochar addition to soil can provide a potential long-term sink for C. SOC increase in tropical sandy soil, clay and sandy clay soil is estimated from 19 to 69 % following biochar application. The limited number of large-scale long-term field experiments and the many aspects that must be considered, make it difficult to estimate the impact of biochar on the SOC sequestration due to its application at global scale

Associated Benefits: The porous structure of biochar enhances the soil's ability to retain water, which can reduce irrigation needs and improve plants' drought resistance. Biochar also increases nutrient availability in the soil, promoting healthier and more vigorous plant growth. However, the impact of biochar on plant growth and yield varies depending on factors such as biochar type, soil characteristics, crop species, and climatic conditions. Additionally, biochar application has been shown to reduce emissions of nitrous oxide (N_2O), a potent greenhouse gas. Furthermore, biochar provides a habitat for beneficial soil microorganisms, improving soil health and enhancing the decomposition of organic matter (Nogués et al., 2023; FAO and ITPS, 2021).

Disadvantages: In some cases, biochar can immobilize nitrogen in the soil, making it less available to plants. Negative effects have been observed on the aggregate stability of clay soils due to the addition of monovalent cations (Pituello et al., 2018). The long-term effects of adding biochar on the soil microbial community are not yet fully understood.

Costs: The production and application of biochar can be expensive, especially if local biomass sources are not available or if the pyrolysis process is not efficient. The cost-effectiveness of applying biochar depends on factors such as carbon prices and government incentives.

Geographical suitability: The application of biochar as a soil fertilizer is permitted in the EU under specific conditions, particularly following the implementation of the updated EU Fertilizer Regulation (2019/1009) of July 16, 2022. Biochar can be applied to a wide range of soils and crops, but it is particularly promising in acidic soils and Mediterranean environments where water scarcity and soil organic matter loss are significant problems (Nogués et al., 2023).

3.5 Sewage sludge

Definition: Sewage sludge is the product derived from the treatment of industrial and urban waters. Before any disposal in fields, the sewage sludge must undergo stabilization and pathogen reduction; these treatments might be chemical, biological or thermic, resulting in a peculiar biosolid composed of water and organic compound. The application of the sewage sludge is highly regulated both at the European level and at the country level, since they might be a vehicle for serious pollutants such as heavy metals (Fe, Cr, Mn, Zn, Hg, Pb, Ni, Cd, and Cu) and organic compounds like endocrines disrupters.

Mitigation Potential: Estimating the mitigation potential of sewage sludge is challenging due to its dose-dependent effects and the limited availability of long-term experimental data. In two long-term experiments conducted in Northern Spain by Roig et al. (2012) and Simões-Mota et al. (2024), the addition of sewage sludge led to an increase in SOC content only at the highest application rate (>80 tC/ha/year). Although the concentrations of toxic elements rose significantly, they remained well below international guideline limits.

Associated Benefits: The application of sewage sludge to agricultural soils offers multiple benefits. It contributes to the sustainability of the water treatment cycle by providing an alternative to disposal methods such as incineration or landfill, both of which are heavily penalized under European Union regulations (Lamastra et al., 2018). Additionally, sewage sludge enhances soil fertility, functioning as an organic fertilizer rich in carbon (C), nitrogen (N), and potassium (K), released in a slow-release form (Mininni et al., 2019; FAO and ITPS, 2021). It also increases pH, electrical conductivity, and cation exchange capacity. Physical properties such as aggregate stability, moisture retention, and porosity are also enhanced, leading to reduced erosion. Moreover, sewage sludge contributes to greater soil biodiversity, particularly microbial biomass. Even in cases where net carbon sequestration is not observed, the addition of treated sewage sludge improves the quality of soil organic matter by enhancing humification processes (Cucina et al., 2019).

Disadvantages: The application of sewage sludge may result in a nutrient cycle imbalance that increases the release of NH_3 and greenhouse gases such as N_2O and CO_2, resulting from a priming effect that can accelerate the decomposition of SOC. The soil may be contaminated with heavy metals and both organic molecules and pathogens (FAO and ITPS, 2021; Lamastra et al., 2018). In addition, the regulatory framework governing the use of sewage sludge is complex and often restrictive (particularly in countries like Italy) where stringent limits on contaminants, trace elements, and application procedures can hinder widespread adoption.

Costs: Farmers incur no cost for the application of sewage sludge, as its disposal is generally managed and financed by the treatment plants, which seek cost-effective and sustainable outlets for the material.

Geographical suitability: Sewage sludge is already widely applied to agricultural soils in several Mediterranean countries, such as Italy and Spain; however, its use is strictly regulated by national legislation to ensure environmental and public health protection (Koumoulidis et al., 2024).

3.6 Digestate

Definition: Digestate is the residue of the anaerobic digestion process, which can originate from livestock effluents, plant biomass, and sewage sludge. The process leads to the production of biogas, mainly CO_2 and CH_4, which is used as an energy source. The by-product, both liquid and solid, is employed in agriculture as a fertilizer. Its characteristics vary greatly depending on the starting material, but in any case, the liquid part is rich in mineral N (i.e., NH4), and the solid part is rich in organic matter whose carbon fraction is considered recalcitrant as it has resisted the digestion process and organic N and P (FAO and ITPS, 2021; Valentinuzzi et al., 2020).

Mitigation Potential: Most of the available studies on the effect of digestate applications on soil organic carbon (SOC) are not long-term. However, several studies with at least three years of observations have recorded an increase in SOC (FAO and ITPS, 2021; Pastorelli et al., 2021; Badagliacca et al., 2022).

Associated Benefits: An adequate application dose can replace synthetic fertilization (Piccoli et al. 2023), also stimulating other soil properties such as aggregate stability and microbial activity (Pastorelli et al., 2021).

Disadvantages: The production of digestate is continuous throughout the year, making it necessary to have storage facilities when it cannot be applied directly to the field for regulatory constrictions (e.g. EU Nitrate Directive), such as winter time for northern Italy. Compared to traditional amendments with manure, digestate risks may cause an increase in salinity and alkalinization of the soil due to its high salt concentration; moreover, it can be a vehicle for contaminants.

Costs: For farms near the digesters (within 20 km) it is estimated a saving of about 100 €/ha considering three applications with digestate compared to ordinary fertilization. Costs can increase or decrease significantly depending on the distance and production (internal or external) of digestate.

Geographical suitability: The European Union is the biggest producer of biogas in the world, and in the Mediterranean basin, Italy stands out due to the production of 30 million tons of digestate. There are no contraindications to the use of digestate in the Mediterranean area.

4 Cultivation practices

4.1 Crop rotations

Definition: Crop rotations are an ancient practice almost as old as agriculture itself and consist of cultivating the same series of crops and/or fallow successively on the same land, with the cycle duration being variable. Since the majority of today's cash crops (>50%) are among the four cereals wheat, maize, rice, and barley, which require high nitrogen inputs, it is good practice to associate them with a leguminous crop in the previous rotation.

Mitigation Potential: Crop rotations generally favor the accumulation of C in the soil, however, different results have been reported in the Mediterranean area. For instance, Spanish Vertisols showed an increase of 23.6 tC/ha after 29 years of rotation (López-Bellido et al., 2020) while the Pianura Padana Plain experienced a 23% increase in SOC stock (Triberti et al., 2016). These effects are attributed to reduced soil disturbance during fallow periods and a decrease in the C:N ratio. Crop rotations were less effective in a 40-year experiment conducted in the Pianura Padana Plain, showing only a modest increase of 0.02 tC/ha/year (Morari et al., 2006).

Associated Benefits: By cultivating diverse crops in succession, soil physical properties improve significantly. Different root systems contribute to soil structure stability, reducing erosion, compaction, and crusting. Vertical root systems, such as those of crucifers, enhance porosity and nutrient transport, while deep-rooted perennials like alfalfa access water and nutrients from deeper soil layers, reducing leaching. The introduction of legumes in rotations not only increases nitrogen use efficiency but also enhances soil biological activity through root exudates and symbiotic relationships with mycorrhizal fungi. These processes boost nutrient cycling, particularly phosphorus, and improve soil organic matter content. Moreover, crop rotations reduce pest and disease pressure by interrupting pest cycles and decreasing plant-parasitic nematodes. This practice also enhances water-use efficiency and reduces the reliance on nitrogen fertilizers, contributing to lower NO2 emissions, a significant greenhouse gas. Rotations can synergize with practices like no-tillage, further improving soil health indicators such as organic matter and microbial activity. Beyond environmental benefits, crop rotations have socio-economic advantages, including diversified income, reduced labor peaks, and cost savings.

Disadvantages: There are no particular disadvantages associated with crop rotations, except for the challenges in implementation due to the lack of markets for secondary products.

Costs: Loss of income from more remunerative crops.

Geographical suitability: The use of this technique is not geographically restricted, except for the choice of species. For example, in the Mediterranean basin, where water availability is limited during the summer months, agricultural production is primarily focused on winter cash crops.

4.2 Increasing root biomass

Definition: Most of the carbon in the soil originates from root systems and their exudates. Root-derived carbon storage is very effective for building a stable SOC stock, since the estimated humification coefficient is 1.9 times higher than above-ground plant materials (Berti et al., 2016). Increasing root biomass is a viable carbon farming strategy because both, highly recalcitrant compounds and those that readily interact with mineral surfaces, contribute significantly to the quantity and quality of soil organic carbon. As noted in Poirier et al. (2018), the amount of root biomass produced is not the sole determinant of SOC; factors such as chemical composition, root diameter, the number of lateral roots, and especially root depth also play crucial roles. Developing carbon farming practices through enhanced root biomass requires research and the adoption of genetically selected crop varieties designed to optimize these traits.

Mitigation Potential: While comprehensive studies on the mitigation potential of genetically selected crops for root biomass in Mediterranean environments are lacking, the impact of selecting for enhanced root traits on carbon sequestration is promising. For instance, high-root-biomass crops like maize have demonstrated an increase in soil organic carbon (SOC) stocks of 0.05-0.15 tC/ha/yearin the cold semi-arid climate of Colorado (Cotrufo et al., 2024). This highlights the significant potential of targeted root trait selection.

Associated Benefits: Larger and deeper root systems provide multiple agronomic and ecological advantages. They contribute to improved crop yields through enhanced uptake of nutrients, water, and gases. Additionally, they promote better soil structure by improving drainage and aeration. These root systems also help reduce erosion caused by wind and water, thanks to the increased stability they confer to the soil. Furthermore, expanded root zones foster greater microbial interaction, enhancing biodiversity in the rhizosphere, which in turn supports more efficient nutrient acquisition and increases disease resistance in crops (Jansson et al., 2021).

Disadvantages: Despite the ratio root:canopy is usually constant irrespectively of the genotype, the knowledge on the effect on yield is still under observation (Heinemann et al., 2023). Lastly, rapid increases in root-derived biomass could trigger priming effects, accelerating the decomposition of existing organic carbon in the soil.

Costs: Increasing root biomass in the soil can be achieved in two ways — by using genetically improved varieties with optimal root morphological traits, or by adopting management practices that promote root development (such as mycorrhizal associations). Both approaches involve additional costs. (Jansson et al., 2021).

Geographical suitability: This strategy is broadly applicable in Mediterranean environments, with no major limitations apart from potential societal concerns regarding the use of genetically engineered crops.

4.3 Conversion to grassland

Definition: The estimated loss of carbon from natural grasslands to arable land in temperate climates is 20-50 tons per hectare (Lal 2003), for this reason in different parts of the world (Set-aside in Europe, Grain for Green in China and the Conservation Reserve Program in the US) the conversion of arable land to grassland is a practice encouraged with the aim of re-accumulating SOC in the soil.

Mitigation Potential: According to Petersson et al. (2025), the potential carbon sequestration due to grassland conversion is estimated at 0.77 tC/ha/year, a value comparable to those reported in FAO and ITPS (2021). In a 50-year long-term experiment in northeastern Italy, the estimated SOC accumulation in a meadow was 0.31 tC/ha/yearhigher compared to a monoculture (Dal Ferro et al, 2020).

Associated Benefits: Grassland provides ecosystem services such as increasing biodiversity, by providing habitat to organisms and wildlife but also increases the aesthetic value of the landscape (FAO and ITPS, 2021). The grasslands itself can be a source of income, as they provide forage for stable livestock or direct grazing.

Disadvantages: The estimates might be inflated because carbon stock measurements are typically conducted only in the top 30 cm of soil. In fact, soils maintained as grasslands for several consecutive years exhibit a significant variation in carbon accumulation along soil depth (Petersson et al., 2025; Dal Ferro et al., 2020). Moreover, in some countries, more croplands might be required to sustain food production for the growing population. If grasslands are used subsequently for grazing, emissions of other greenhouse gases by the livestock, such as N2O and CH4, could offset the beneficial effects on carbon stock.

Costs: It usually results in a loss of income for farmers, especially in the case of first years when grasslands should not undergo heavy grazing (FAO and ITPS, 2021); therefore, such measures must be supported by institutional incentives.

Geographical suitability: There is no limit to the applicability of the practice; it is suggested to identify those soils highly depleted in C stock because they have higher accumulation potential of C.

4.4 Cover cropping

Definition: Any plant species that is grown between two periods of normal crop production, or between trees in orchards and vineyards (MeeTINGS, 2008). Their purpose is to protect the soil from erosion, avoiding a period of bare soil. The cover crops are usually plowed into the soil before the production crop is sown (green manure). Typical cover crops are legumes, brassicas, and grasses. It is not unusual to have mixtures of two or more species, looking for synergistic effects.

Mitigation Potential: A meta-analysis of cover crops in woody crops in the Mediterranean basin (Vicente-Vicente et al., 2016) estimates an additional C storage of 1.03 tC/ha/year. An updated meta- analysis of the study sites shown in Fig. 2 estimates an increase of 45% in SOC content after an average 9.4-year period.

Associated benefits: Cover crops, in addition to protecting the soil from erosion, enhance biodiversity, act as suppressants of weeds and might help to control pests and diseases.

Disadvantages: The water use of the cover crops might be excessive and this could damage the following cash crop. This is particularly true in semi-arid regions (Blanco et al., 2015). In some cases, the incorporation of the residues might have a priming effect (Camarotto et al., 2020), and this leads to a reduction in SOC content and alters the C/N ratio. The residues can interfere with the spring crop by impeding the seeds from contacting the soil.

Costs: The costs of cover crops include seed purchase, sowing, and termination. All these operations have two main costs: fuel and labour, that have been estimated to range from 18.1 €/ha in the case of direct seeding and no tillage to 58 €/ha in the case of conventional tillage and seeding in an Italian farm (Calcante et al., 2022). Additionally, mixed seeds tend to be more expensive than monoculture (McGuire, 2018).

Geographical suitability: Although cover crops contribute to the preservation of soil quality and fertility, it is reported that in semi-arid regions, such as certain zones of the Mediterranean basin, the possible competition of cover crops for available soil water can limit the adoption of the practice.

4.5 Intercropping

Definition: Intercropping is an agricultural practice involving the simultaneous cultivation of multiple plant species on the same land area (Aguilera-Huertas et al., 2024; FAO and ITPS, 2021). It is a key component of crop diversification, one of the three core principles of Conservation Agriculture. Intercropping is considered a sustainable strategy for improving productivity and soil quality.

Mitigation Potential: In the Mediterranean region, intercropping has shown promising potential for enhancing soil organic carbon (SOC) storage (Aguilera-Huertas et al., 2024; Almagro et al., 2023). In rainfed olive orchards, alley cropping combined with minimum tillage led to increases in SOC within the topsoil layer (0–10 cm) in just three years. Similar effects on SOC and nitrogen have also been observed in irrigated almond and mandarin systems (Almagro et al., 2023).

Associated Benefits: Intercropping can improve soil structure, including aggregate stability. It enhances water and nutrient use efficiency, and can increase both soil biodiversity and microbial activity (Aguilera-Huertas et al., 2024). The practice may also boost total crop yield and yield stability over time. Including legumes in intercropping systems can improve soil fertility and reduce the need for nitrogen fertilizers. These benefits are amplified when intercropping is combined with other sustainable practices (FAO and ITPS, 2021).

Disadvantages: Outcomes of intercropping can be uncertain and are highly dependent on site-specific conditions such as soil type and climate. In some cases, intercropping may lead to higher N_2O emissions compared to monoculture systems. When crop competition is intense, yield gains from intercropping might come at the expense of one of the component crops (i.e, crop grown alongside the base crop in lesser amount). Additionally, no significant improvement in aggregate stability or soil C/N concentrations is noticeable after short term of application when intercropping is used alone (Reichmann et al., 2025). Lastly, management of two, often contrasting, crops is inefficient. Especially, but not only, when cultivating annuals with perennials

Costs: Initial high costs related to purchasing specialized equipment for seeding or managing residues can be a barrier. Another potential challenge is the difficulty of using large-scale mechanization (FAO and ITPS, 2021).

Geographical suitability: Intercropping is applicable across a wide range of soil-climatic conditions and cropping systems, including both herbaceous and woody crops such as almonds, mandarins, olives, and vineyards. Its effectiveness varies based on local conditions, requiring site-specific adaptation of practices. Adoption may be limited in low-productivity areas due to insufficient biomass availability (FAO and ITPS, 2021).

5 Cultivation systems

5.1 Agroforestry

Definition: Agroforestry is a type of agricultural system that integrates the cultivation of perennial trees and/or shrubs with arable land and/or pasture within the same area. Unlike simple intercropping systems, such as olive and wheat, the defining feature of agroforestry lies in the deliberate inclusion of non-commercial or native woody species, which are not primarily grown for harvest but for their ecological functions. In Mediterranean conditions, the use of small trees and shrubs from the natural vegetation, for example, arranged as hedgerows along tree orchards, offers significant advantages, including enhanced biodiversity, microclimate regulation, and erosion control, which often outweigh the minor loss of cultivated area.

Mitigation Potential: It is estimated that if worldwide 10% arable land were covered with trees, approximately $18x10^9$ tons of carbon could be sequestered through the increased biomass. SOC is primarily increased by litterfall, root turnover, and exudates, and enhanced physical stabilization of organic matter due to improved soil aggregation (Zomer et al., 2022; FAO and ITPS, 2021). In Italy, an increase of 78% in SOC was reported in an agroforestry ecosystems implemented with hedgerows (Chiaffarelli et al., 2024); however, a decrease in C stock was observed when the agroforestry system was coupled with sheep grazing (Bateni et al., 2021).

Associated Benefits: The consociation of trees and hedgerows with cash crops on arable land provides shelter and nutrients for animals, which increases biodiversity and promotes biological control of pests. At the same time, the effects of trees on soils are not limited to carbon sequestration, in fact with their root system, they provide better aeration, water retention, reduced runoff of chemical inputs and erosion control (Borin et al., 2005, Ghale et al., 2022; Scordia et al., 2023).

Disadvantages: Mechanization is more difficult in agroforestry than in conventional systems. The reduction in arable area and the decreased light penetration to crops can lead to yield reductions—up to 42% in Mediterranean cereal production compared to monocultures (Arenas-Corraliza et al., 2022). This highlights the need to select shade-tolerant crop varieties when implementing agroforestry. However, the extent of shading depend on factors such as the height of the hedgerow, which is usually no more than 1.5 meters. Additionally, in semi-arid climates, such as those found in parts of the Mediterranean region, the increased water demand of agroforestry systems can pose significant economic and environmental challenges (Temani, 2020).

Costs: The operating costs are reported to increase by 16% (Rezgui et al., 2024).

Geographical suitability: Several agroforestry systems have historically been implemented in the Mediterranean area, such as the ”Viti maritate” (i.e., grape vines on living trellis) in Italy, ”Dehesa” (i.e., agrosylvopastoral systems) in Spain and consociations between cereals and olive groves in Greece. According to Fotakis et al. (2024), approximately 30% of the Aegean and Adriatic regions and 22% of the Iberian Peninsula are suitable for conversion to silvopastoral systems.

5.2 Organic farming

Definition: Organic farming is a system that avoids the use of artificial inputs such as fertilizers, herbicides, and pesticides. It depends on animal manures, crop rotations, crop residues, biological and non synthetic mineral pest control, and biological systems of nutrient mobilization from the soil.

Mitigation Potential: Due to the consistent use of practices such as the application of organic fertilizers, use of cover crops and use of leguminous crops in rotations, on average, organic farming sequester approximately 287kg/ha more C than conventional systems (Tiefenbacher et al., 2021). A global meta-analysis of 68 datasets confirmed that organic fertilization is the most influential factor in SOC accumulation within organic farming.

Associated benefits: Organic farming offers a holistic approach to sustainable agriculture, enhancing soil health through crop rotation, organic amendments, and increased organic matter. It supports soil biodiversity by boosting microbial abundance and activity while reducing chemical input use (it is allowed the use of naturally derived pesticides like pyrethrins, copper, and sulfur). These systems build resilience to climate change by improving water retention and temperature tolerance. Organic practices reduce environmental impacts by lowering greenhouse gas emissions, reducing water contamination, and decreasing soil erosion. Socio-economically, organic farming generates rural employment, lowers input costs, and its products can be sold with a mark-up (FAO and ITPS; 2021, Reeve et al., 2016).

Disadvantages: Nutrient imbalances (e.g. P surplus) can occur if organic systems lack proper management, especially without adequate fertilization or cover crops. Organic systems often rely on limited external inputs and biological nitrogen fixation, which can lead to long-term soil fertility deficits. Sustainable nutrient management is crucial to support productivity and the sector's future expansion (Reimer et al., 2024).

Economic and cultural barriers also hinder adoption, including high certification costs, lack of government support, and limited consumer awareness in some regions. Intercropping and agroforestry may lead to yield trade-offs due to competition or shading. In Mediterranean regions, reduced tillage can increase erosion due to run-offs or weed pressure compared to no-till, if not combined with proper ground cover. High initial costs, limited technical knowledge, and social resistance to new methods also act as barriers. Moreover, local conditions such as soil type, slope, and water availability can limit the applicability of certain organic practices.

Costs: Economically, organic farming often outperforms conventional farming, despite its significantly higher labor costs. This is generally due to the higher market prices that organic products command. However, it is important to consider that organic farming typically results in lower yields, so a thorough cost-benefit analysis is necessary (Durham and Mizik, 2021). In some cases of organic farming, such as ovine production in Greece, a dependency of these systems on European subsidies has been noted (Tzouramani et al., 2011).

Geographical suitability: In Mediterranean Europe, organic farming can be applied without major restrictions. In Italy, nearly 8% of farms have already converted to this method of production. Most organic farming consists of arable crops (42%) and grasslands and pastures (30%), while perennial crops (23%) and vegetables (2.5%) are still struggling to grow. In Italy, southern regions continue to dominate organic production, accounting for 58% of the national total, compared to 21.3% in central Italy and 20.5% in the north (ISPRA, 2023).

5.3 Conservation Agriculture

Definition: Conservation Agriculture (CA) is founded on three pillars: minimizing soil disturbance through practices such as no-tillage or minimum tillage, maintaining permanent soil cover using crop residues or cover crops, and diversifying crop species through rotations that include at least three different crops (Valkana et al., 2020). These principles work together to improve soil structure, protect against erosion, and foster ecological balance.

Mitigation Potential: In Mediterranean and humid subtropical climates, CA has demonstrated a measurable capacity to enhance soil organic carbon (SOC) stocks, particularly in the upper 30 cm of soil. On average, CA increases SOC by approximately 12% compared to conventional agricultural systems, which corresponds to a carbon sequestration rate of about 0.48 tC/ha/year. In soils that initially contain low levels of organic carbon (≤ 40 Mg C ha^{-1}), the benefit is even more pronounced, with SOC increases reaching up to 20%. If CA were widely adopted across the European zones within these climatic zones, it could result in the sequestration of approximately 0.15 Pg of carbon per year in topsoil (Tadiello et al., 2022). However, it has been put forward that the greater C content in conservation agriculture fields may be an artefact of shallow sampling and that, after considering deeper soil profiles, CA would not show any advantages in C sequestration with respect to conventional tillage (Ogle et al.,2012). Experiments carried out in NE Italy, confirmed this postulate, since a positive effect of CA on SOC stocks was observed only in the top 0–20 cm of soil, while no significant change was noted considering the deeper layers (i.e., 20-50 cm) (Piccoli et al., 2016).

Associated benefits: Beyond its carbon sequestration potential, CA offers a broad range of agronomic and environmental benefits. It promotes biodiversity and enhances biological activity in the soil, leading to improved nutrient cycling and soil resilience. The presence of permanent soil cover and reduced disturbance improves water retention and nutrient use efficiency, which can increase crop yields and reduce yield variability over time. In addition, CA contributes to climate change mitigation by reducing greenhouse gas emissions, both through carbon storage and by lowering the frequency and intensity of mechanical operations. In the Veneto region of Italy, studies have shown that CA systems with cover crops can reduce water percolation by up to 30% compared to conventional systems (Camarotto et al., 2018; Piccoli et al., 2016).

Disadvantages: Despite its potential, the effectiveness of CA can vary significantly depending on site-specific conditions, such as soil type, climate, and management history. In some cases, minimum tillage may lead to short-term reductions in SOC, especially during the initial transition from conventional systems. Additionally, certain studies have reported a possible increase in soil compaction and in turn to nitrous oxide (N_2O) emissions, which could offset some of its climate benefits. CA also tends to be less effective in soils that already have high levels of organic carbon (i.e., above 40 tC/ha), where additional sequestration potential is limited (Tadiello et al., 2022).

Costs: Economic assessments suggest that CA can reduce production costs for farmers, mainly by lowering fuel and labor expenses associated with tillage operations. These cost savings may contribute to greater financial sustainability, particularly in the long term (Valkana et al., 2020).

Geographical suitability: Conservation Agriculture is particularly suitable for soils with low initial SOC content (≤ 40 tC/ha), self-structuring and in mid-latitude or semi-arid regions characterized by Mediterranean or humid subtropical climates. Its benefits are maximized when implemented over the long term; for instance, it may take around ten years to achieve a 20% increase in SOC in carbon-poor soils (Camarotto et al., 2018; Tadiello et al., 2022).

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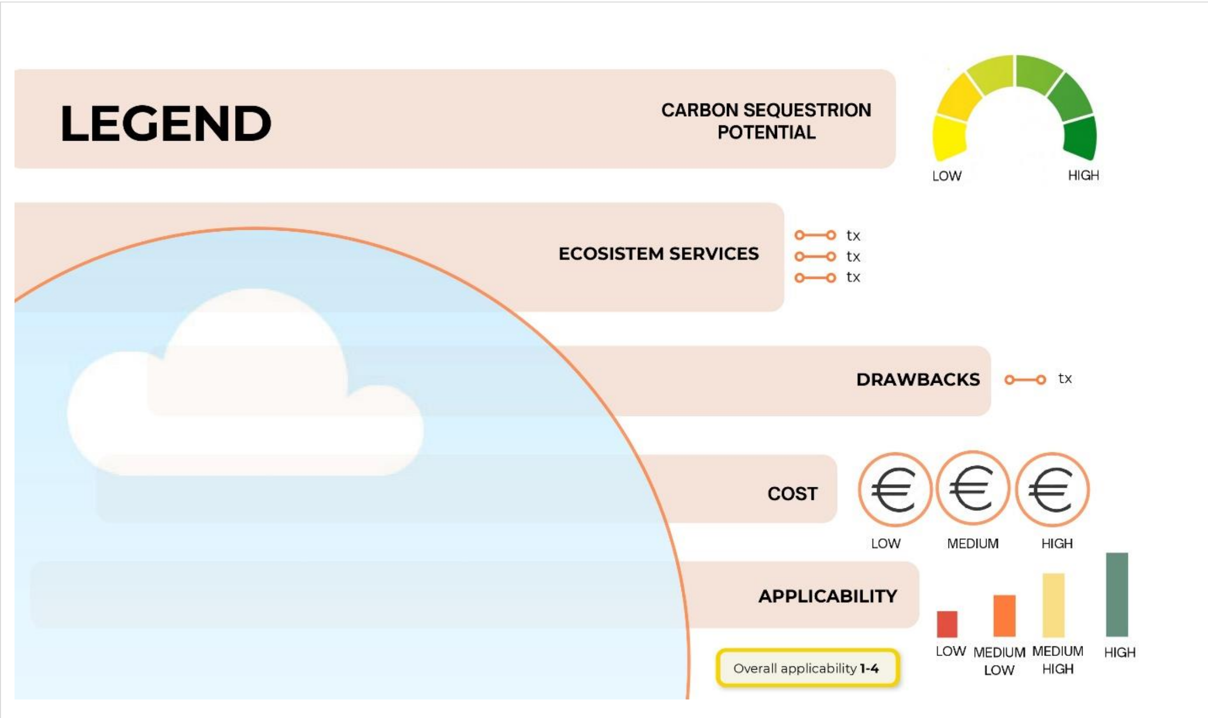
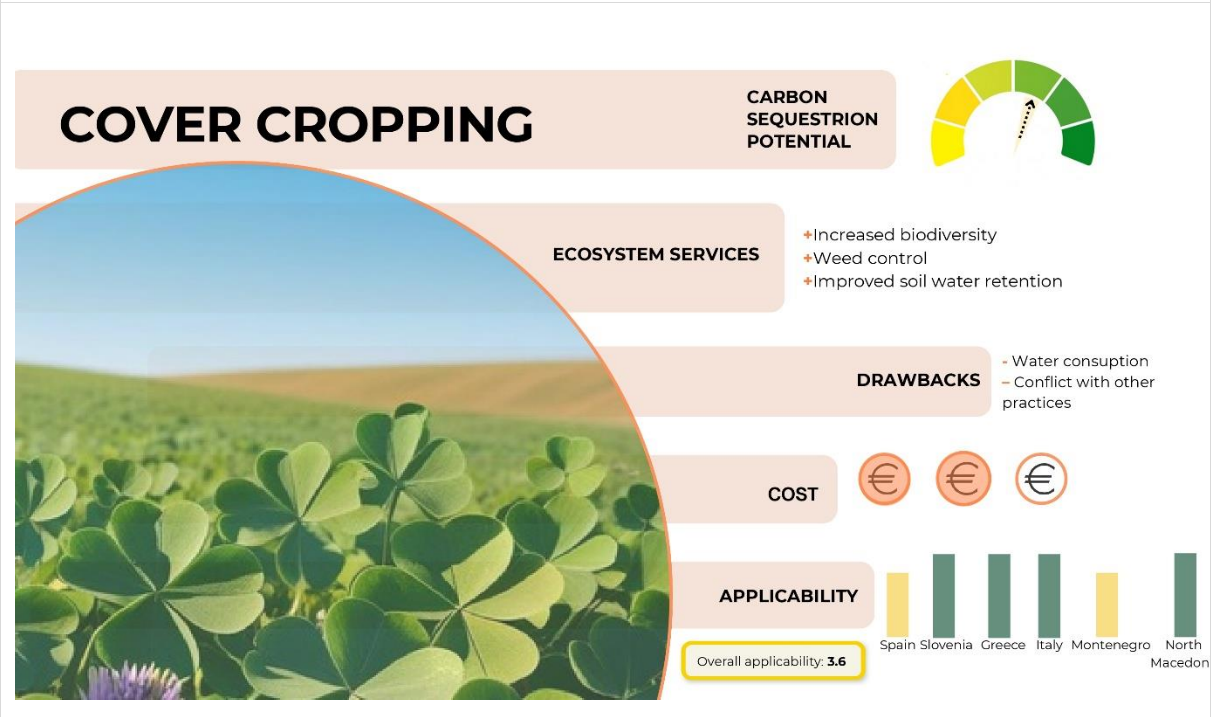
ANNEX I: BMPs IN GRAPHICS





ORGANIC MULCHING

CARBON SEQUESTRION POTENTIAL

ECOSYSTEM SERVICES

+ increased biodiversity
+ weed control
+Decrease water evaporation
+increase aggregate stability

DRAWBACKS

– Induced alleolpathy
– Only implemented in no-till systems

COST

APPLICABILITY

Overall applicability: **2.6**

NO TILLAGE

CARBON SEQUESTRION POTENTIAL

ECOSYSTEM SERVICES

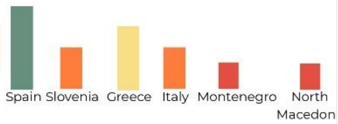
+ Reduced erosion
+ Increased water retention
+Enhanced soil biodiversity

DRAWBACKS

– Use of chemical herbicides
– Soil compaction
–Yield reduction
– Need for specific equipment

COST

APPLICABILITY



Overall applicability: **2.1**

CONSERVATION TILLAGE

CARBON SEQUESTRION POTENTIAL

ECOSYSTEM SERVICES

+ reduced erosion
+ increased aggregate stability
+ increased resilience to temperature and moistu fluctuations

DRAWBACKS

– Reduced weed control
– Soil compaction
– Yield reduction
– Need for specific equipment

COST

APPLICABILITY

Overall applicability: **3**

MANURE ADDITIONS

CARBON SEQUESTRION POTENTIAL

ECOSYSTEM SERVICES

+ Decreases soil bulk density
+ Improves aggregate stabiility and water retention
+ Slow relaese of nutrients

DRAWBACKS

– Excess in P apport which can cause eutrophication
– Nitrate leaching
– Accumulation of trace elements-salts

COST

APPLICABILITY

Overall applicability: **3.3**

CROP RESIDUES

CARBON SEQUESTRION POTENTIAL

ECOSYSTEM SERVICES

+ Enhanced soil structure and aggregate stability
+ Reduced soil erosion
+ Source of nutrients

DRAWBACKS

– Emergency slowed down
– High C:N residues might immobilize N

COST

APPLICABILITY

Overall applicability: **3.3**

COMPOST

CARBON SEQUESTRION POTENTIAL

ECOSYSTEM SERVICES

+ Enhanced soil structure and aggregate stability
+ Suppression of pests and diseases
+ Source of nutrients
+ Increases crop yield and quality

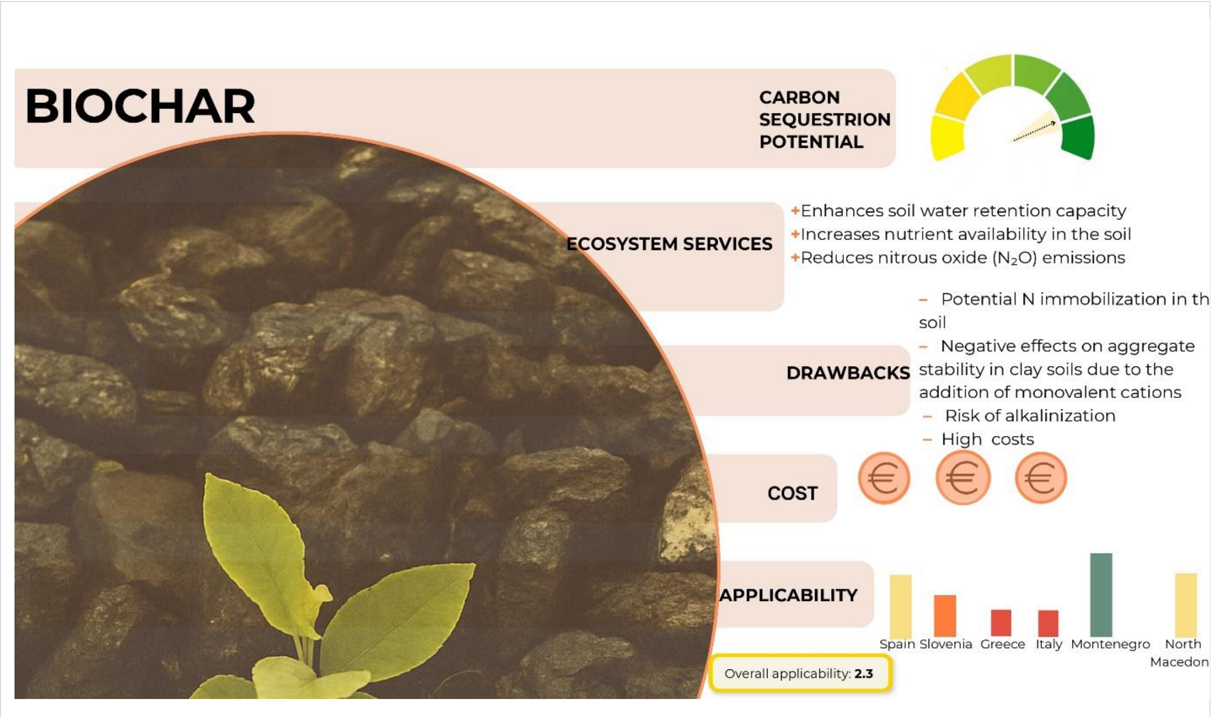
DRAWBACKS

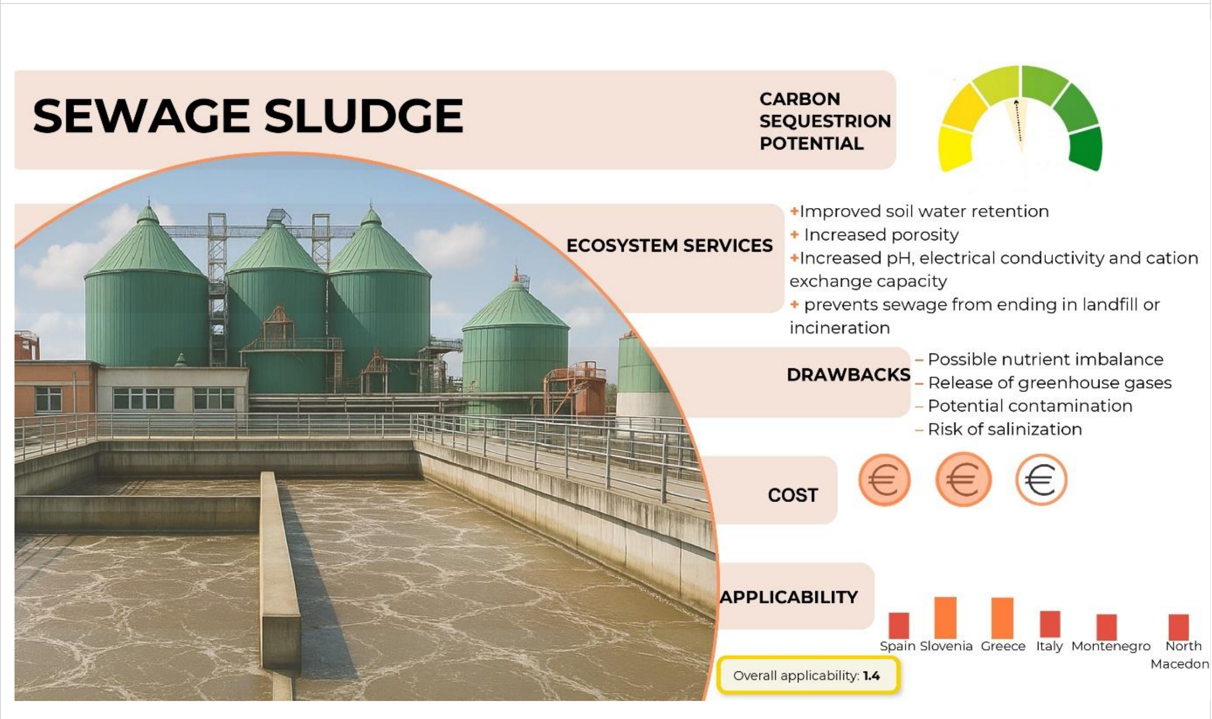
– Compost might be source for heavy metals and organic pollutants
– First years of adoption yield decrease

COST

APPLICABILITY

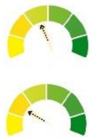
Overall applicability: **2.6**


BIOCHAR
CARBON SEQUESTRION POTENTIAL
ECOSYSTEM SERVICES
+Enhances soil water retention capacity
+Increases nutrient availability in the soil
+Reduces nitrous oxide (N2O) emissions
DRAWBACKS
– Potential N immobilization in th soil
– Negative effects on aggregate stability in clay soils due to the addition of monovalent cations
– Risk of alkalinization
– High costs
COST
APPLICABILITY
Spain Slovenia Greece Italy Montenegro North Macedon
Overall applicability: 2.3


SEWAGE SLUDGE
CARBON SEQUESTRION POTENTIAL
ECOSYSTEM SERVICES
+Improved soil water retention
+ Increased porosity
+Increased pH, electrical conductivity and cation exchange capacity
+ prevents sewage from ending in landfill or incineration
DRAWBACKS
– Possible nutrient imbalance
– Release of greenhouse gases
– Potential contamination
– Risk of salinization
COST
APPLICABILITY
Spain Slovenia Greece Italy Montenegro North Macedon
Overall applicability: 1.4

DIGESTATE

CARBON SEQUESTRION POTENTIAL



ECOSYSTEM SERVICES

+ Improved aggregate stability
+ Increased microbial activity
+ An adequate dose could replace mineral fertilizers

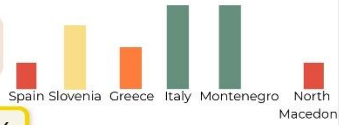
DRAWBACKS

– Producted year round, it has to be stored in some facilities
– Vehichles for contaminants
– Risk of salinization and alkalinization

COST

€ € €

APPLICABILITY



Overall applicability: **2.4**

AGROFORESTRY

CARBON SEQUESTRION POTENTIAL

ECOSYSTEM SERVICES

+ Shelter and nutrients for animals, increased biodiversity
+ Increased biological control
+ Trees root systems provide better aeration, water retention, reduced runoff of chemical inputs and erosion control

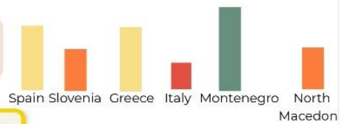
DRAWBACKS

– Competition for light, water and nutrients
– Preduction of arable area with reduction in yields
– Mechanization is hampered

COST

€ € €

APPLICABILITY



Overall applicability: **2.5**

CROP ROTATIONS

CARBON SEQUESTRION POTENTIAL

ECOSYSTEM SERVICES

+ Improved soil structure
+ Diversified income
+ Legumes enhance nitrogen efficiency and soil microbiota
+ Reduced pest and disease pressure
+ Increased biodiversity
+ Lower erosion

DRAWBACKS

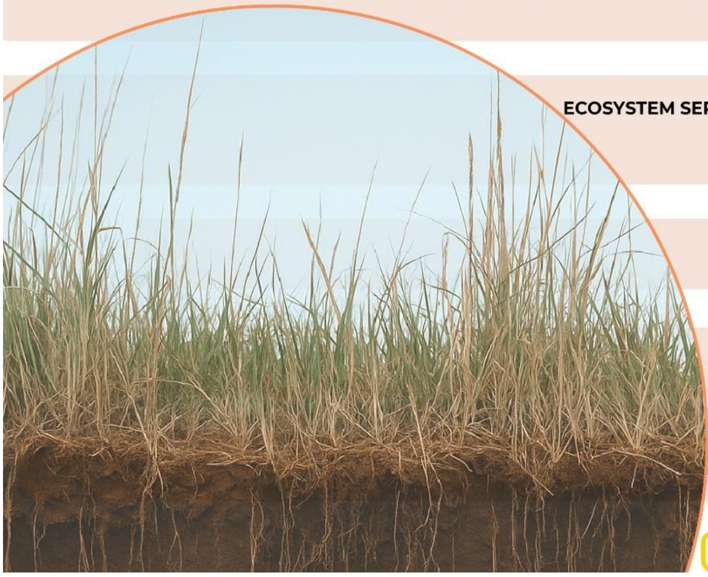
– Challenges may arise in the market of secondary crops

COST

APPLICABILITY

Overall applicability: **3.8**

INCREASING ROOT BIOMASS



ECOSYSTEM SERVICES

+ Improved soil water retention
+ Increased porosity
+ Greater microbial interacion and enhanced utrient acquisition
+ Reduced erosion

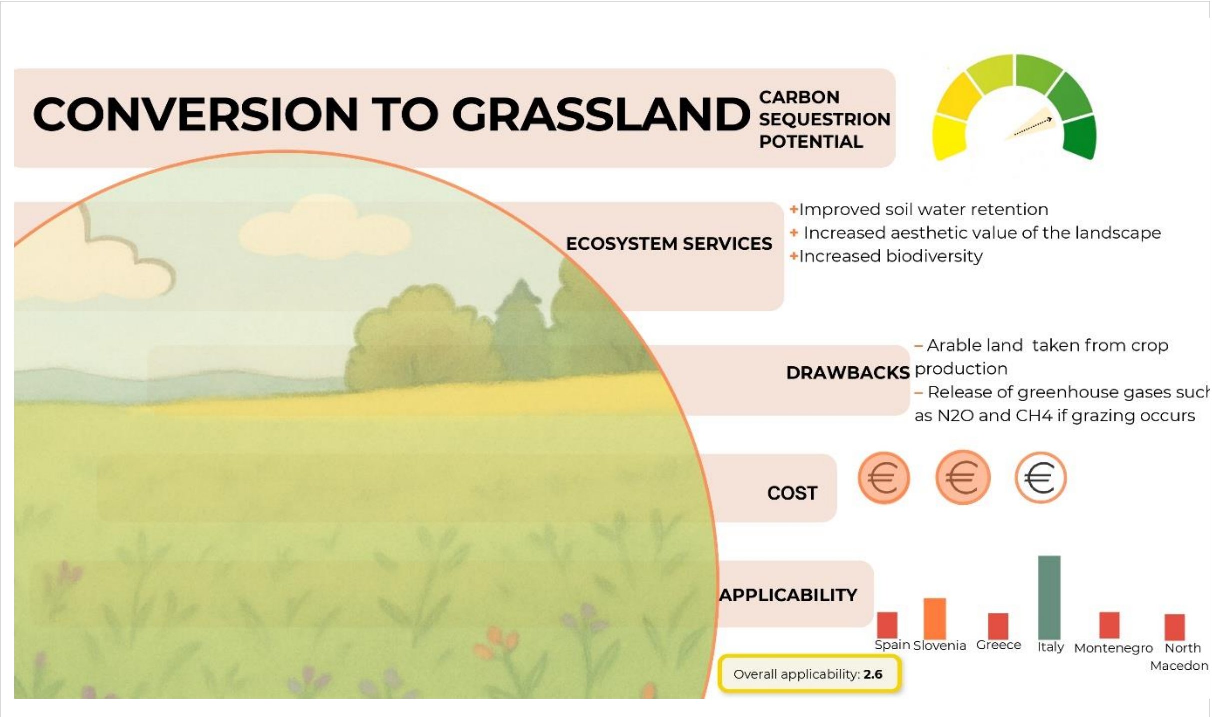
DRAWBACKS

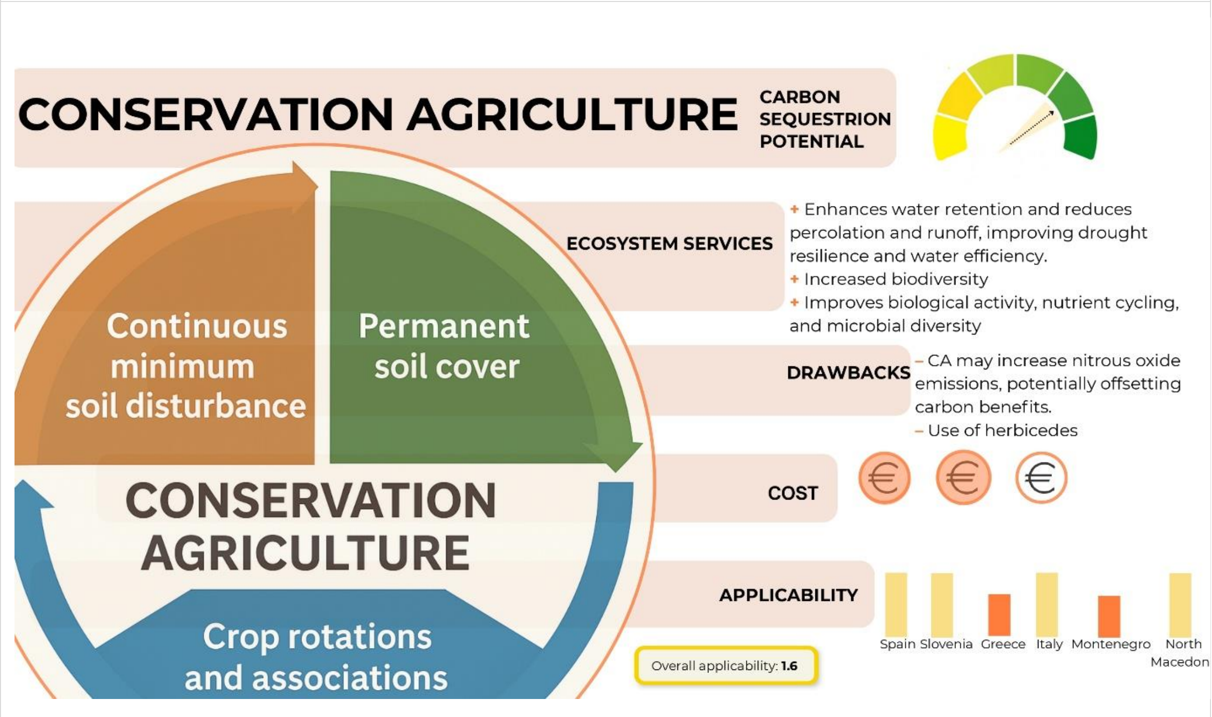
– Risk of roots reaching groundwater and bringing up the water table
– Risk of reduced above ground production
– Rapid increase in root biomass could trigger a priming effect

COST

APPLICABILITY

Overall applicability: **2.6**


CONVERSION TO GRASSLAND
CARBON SEQUESTRION POTENTIAL
ECOSYSTEM SERVICES
+Improved soil water retention
+ Increased aesthetic value of the landscape
+Increased biodiversity
DRAWBACKS
– Arable land taken from crop production
– Release of greenhouse gases such as N2O and CH4 if grazing occurs
COST
APPLICABILITY
Spain
Slovenia
Greece
Italy
Montenegro
North Macedon
Overall applicability: 2.6


CONSERVATION AGRICULTURE
CARBON SEQUESTRION POTENTIAL
Continuous minimum soil disturbance
Permanent soil cover
CONSERVATION AGRICULTURE
Crop rotations and associations
ECOSYSTEM SERVICES
+ Enhances water retention and reduces percolation and runoff, improving drought resilience and water efficiency.
+ Increased biodiversity
+ Improves biological activity, nutrient cycling, and microbial diversity
DRAWBACKS
– CA may increase nitrous oxide emissions, potentially offsetting carbon benefits.
– Use of herbicedes
COST
APPLICABILITY
Spain
Slovenia
Greece
Italy
Montenegro
North Macedon
Overall applicability: 1.6

ORGANIC FARMING

CARBON SEQUESTRION POTENTIAL

ECOSYSTEM SERVICES

+Improved soil water retention
+ Increased aesthetic value of the landscape
+Increased biodiversity

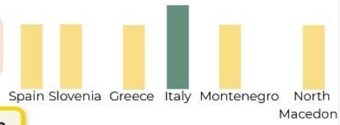
DRAWBACKS

– Arable land stolen to crop production
– Release of greenhouse gases such as N2O and CH4 if grazing occurs

COST

€ € €

APPLICABILITY



Overall applicability: **3.2**

INTERCROPPING

CARBON SEQUESTRION POTENTIAL

ECOSYSTEM SERVICES

+Improved Soil Structure and Fertility
+Increases aggregate stability and microbial activity particularly when legumes are included.
+Promotes biodiversity and improves water and nutrient use efficiency.

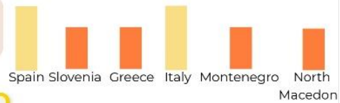
DRAWBACKS

– High competition between crops may reduce the yield of one component crop

COST

€ € €

APPLICABILITY



Overall applicability: **2.3**