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Allianz Research

# Ashes to ashes, carbon to soil

## A cost-benefit analysis of abatement measures to increase soil carbon-sequestration capacity

# Executive Summary

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- The biodiversity financing gap exists mainly due to a knowledge gap: the valuation of ecosystem services. Ecosystem services are the direct and indirect contributions ecosystems (known as natural capital) provide for human wellbeing and quality of life. This can be in a practical sense, such as providing food and water or regulating the climate. We understand that the productivity and regulatory functions of ecosystems are of great value to our economic sectors, but we have little understanding of the price tag of this value, let alone the abatement costs (and benefits) of declining ecosystem services.
- One of the most important ecosystem services is provided by soil as carbon sinks for climate regulation, storage for organic carbon and aid in regulating atmospheric carbon dioxide levels. Effective carbon pricing mechanisms, such as carbon offsets, are essential to fund activities that improve soil quality and sequester carbon, thereby closing the biodiversity financing gap and promoting economically viable environmental practices. The EU Soil Strategy 2030 and the EU Carbon Removals Certification Framework are critical initiatives aimed at increasing soil organic carbon (SOC) content and achieving land-based climate neutrality by 2035. These efforts are crucial for transitioning to a climate-neutral economy.
- In order to determine the socio-economic value of soil in Europe as a source of carbon sequestration, we refer to the conservative estimates of the global cost of carbon by the COACCH project, which is USD132 per tCO2-eq[1] globally. This leads to a socioeconomic value of about USD18.3trn (1.1x Europe's GDP) through the GHG emission channel. This ranges from about USD26bn in Malta to USD3.2trn in Sweden.
- Virtuous soil management practices present significant carbon offsetting – and thus transition – opportunities for the financial sector. This study examines five soil improvement measures — three crop management practices (cover cropping, no tillage and use of green manure) and two broader land restoration techniques (agroforestry and sustainable forest management) — that can enhance soil quality, in six countries: Germany, France, the Netherlands, Italy, Spain and the UK. All these measures contribute to preventing soil erosion, enhancing carbon sequestration, and improving biodiversity.
- The total required investment for these five levers is estimated to be USD32.7 bn (present value of current and future measures) and ranges from USD 13mn for forest management in the Netherlands to USD 4.1  for cover cropping in France. These costs are primarily influenced by the land size available in countries, expected adoption rates and implementation costs per hectare. Note that it takes five to ten years for these soil management practices to provide their full benefits. The socioeconomic benefits are much higher, reaching USD 6.7bn for no tillage and USD5.1bn for green manure in France. Therefore, the majority of measures can be considered 'no regret' moves as they are cost-effective and have much higher socioeconomic values than the investment required to implement them.

[1] The term tCO2-eq refers to CO2 equivalents and converts other greenhouse gases like methane into CO2 equivalents by using the 100 years global warming potentia

# The knowledge gap

Financial institutions are mandated to undertake biodiversity-related stress tests and portfolio analyses, as well as develop strategies concerning biodiversity.[2] These activities are crucial under the Corporate Sustainability Reporting Directive (CSRD), which mandates all large and listed companies – except for listed micro-enterprises – to report on perceived risks and opportunities stemming from social and environmental issues, as well as the impacts of their operations on society and the environment. While there is a general awareness, understanding, and access to measurement tools among economic decision-makers, such as governments and financial institutions, regarding the impacts of climate change, knowledge about the interplay between biodiversity loss and the economy remains limited. Moreover, there are untapped opportunities to transition to a zero-biodiversity-loss economy. This knowledge deficit contributes to a significant biodiversity financing gap, largely due to a lack of understanding of how to value ecosystem services[3] (ES). These services play an essential role in supporting life on Earth and provide immense value to economic sectors. However, there is scant comprehension of how to price these services, much less the costs and benefits associated with mitigating the decline of ecosystem services. This issue is particularly critical in soil, one of the most vital biodiversity ecosystems.

[2] As highlighted by ECB (2020) and ECB (2022).

[3] Ecosystem services are the benefits that humans derive from various aspects of nature and ecosystems. Better soil quality, for instance, benefits humans by increasing crop production and storing carbon dioxide from the atmosphere. These services are broadly categorized into four main types:

1.Provisioning services: These include the products obtained from ecosystems, such as food, water, timber, fiber, and genetic resources.

2.Regulating services: These are the benefits obtained from the regulation of ecosystem processes, such as climate regulation, disease regulation, water purification and pollination.

3.Supporting services: These services are necessary for the production of all other ecosystem services. They include soil formation, nutrient cycling and primary production.

4.Cultural services: These include non-material benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences.

# Ecosystem services of soil

Healthy soil supports a vibrant living system of diverse soil organisms, benefiting crop production as well as reducing greenhouse gas emissions and mitigating climate change. There are four main channels through which soil contributes to the well-being of both natural and human systems:

**Climate regulation:** Soils act as a carbon sink for climate regulation, storing organic carbon and helping regulate atmospheric carbon dioxide levels. Soil can influence the microclimate through thermal properties, impacting temperature and humidity (FAO, 2015b; Berryman et al., 2020).

**Nutrient mediation:** Soils serve as a reservoir and mediator of essential nutrients (nitrogen, phosphorus, potassium, etc.) for plants and microorganisms. Hence, microbial activity in the soil is necessary for decomposing organic matter and releasing nutrients for plant uptake (FAO, 2022).

**Biodiversity and habitat:** Soils provide habitat and sustenance for diverse organisms, from microscopic bacteria and fungi to larger organisms such as earthworms. Therefore, biodiversity in the soil contributes to ecosystem stability and resilience (European Commission, 2010).

**Water filtration and purification:** Soils are essential in water filtration and purification, helping to maintain water quality. They also regulate water flow, reducing the risk of flooding by absorbing and slowly releasing water (FAO, 2015c).

Global challenges such as population growth, urbanization, land use changes, economic expansion and conflict place significant stress on soil resources. These factors contribute to soil degradation through erosion, loss of soil organic carbon (SOC), contamination and increased soil salinity and acidity. Such degradation affects approximately 20-40% of the world's total land area, impacting croplands, drylands, wetlands, forests and grasslands, potentially affecting nearly half of the global population (FAO and ITPS, 2015; FAO, 2021; UNCCD, 2022b). A recent study by Pravalie et al. (2021) highlights that Asia leads in SOC decline, accounting for 33.5% of global reductions. South America follows with a 22.9% decrease, cumulatively representing over 55% of the global decline. Europe, North and Central America and Africa have also experienced significant decreases of 16.9%, 13.6%, and 11.9% respectively, while Australia and Oceania maintained a neutral SOC balance.

Soil degradation poses significant economic and financial risks, particularly through the diminished capacity of soil to retain water and nutrients, which can adversely affect crop production and economic activities (FAO and ITPS, 2015; UNCCD, 2022a). Conversely, soil's carbon-sequestration capability offers substantial opportunities to reduce global greenhouse gas emissions. In response, the EU Soil Strategy 2030 has set forth initiatives to increase SOC content in agricultural lands, aiming for land-based climate neutrality in the EU by 2035 and contributing to a climate-neutral Europe by 2050 (Maes et al., 2020; Paul et al., 2023). This strategy is supported by the EU Carbon Removals Certification Framework[4],which seeks to certify carbon-removal activities within the EU. These activities, including carbon farming practices such as no-till farming, cover cropping, and the use of green manure, enhance the soil's capacity to store organic matter and carbon, thereby aligning with broader climate objectives.

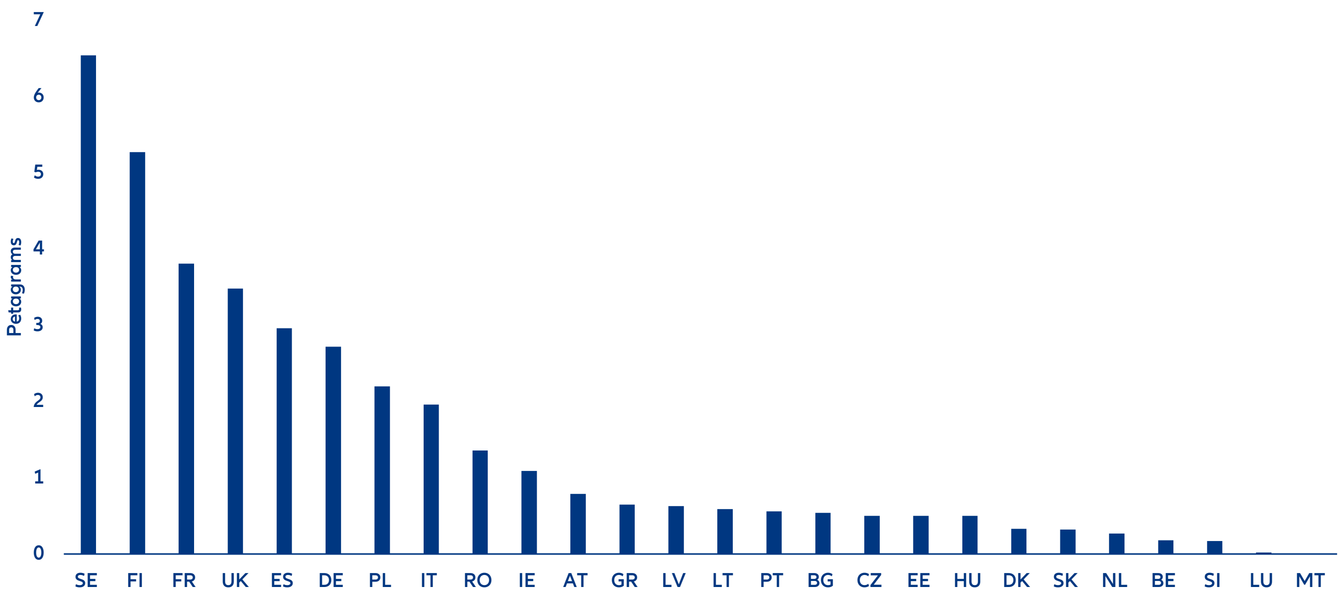
[4] For the full European Council announcement: https://www.consilium.europa.eu/en/press/press-releases/2024/02/20/climate-action-council-and-parliament-agree-to-establish-an-eu-carbon-removals-certification-framework/

# The social costs of soil organic carbon (SOC) loss

This study summarizes the findings on the social costs of SOC loss on a global scale through carbon sequestration channels, leveraging existing estimates of the social cost of carbon and literature on carbon-sequestration capabilities. Subsequently, the study identifies measures to restore soil quality and estimates the costs of these abatement measures, comparing them with the monetized benefits derived from carbon-sequestration channels. Indeed, the broader social costs of soil quality loss become more pronounced when considering all ecosystem services supported by soil, such as flood risk protection and other threats to soil quality. Thus, this study represents an initial step in this exploratory endeavor.

To estimate the social cost of SOC loss associated with increased greenhouse gas emissions, the study employs hypothetical scenarios based on SOC topsoil stock levels, utilizing data for European countries (EU member states, including the UK but excluding Croatia and Cyprus) from 2013 (Yigini & Panagos, 2016) as illustrated in Figure 2[5].These estimations represent the total SOC stocks across various land types in the topsoil layer (0-20 cm depth). For this analysis, SOC stocks from all land types are considered together, acknowledging that reductions in carbon sequestration occur not only in agricultural soils but also in non-agricultural soils such as forests and wetlands due to climate change and land use changes (Brillouin et al., 2023). Global annual SOC loss is estimated at 58.6 tons C per square kilometer per year (Pravalie et al., 2021).

**Figure 1:** Absolute SOC stock levels in European countries, 2013




Sources: Yigini and Panagos (2016), Allianz Research.

Notes: BE Belgium, BG: Bulgaria, CZ: Czechia. DK: Denmark, DE: Germany, EE: Estonia, IE: Ireland, EL: Greece, ES: Spain. FR: France. HR: Croatia. IT: Italy. CY: Cyprus LV: Latvia, LT: Lithuania, LU: Luxembourg, HU: Hungary, MT: Malta, NL: Netherlands, AT: Austria, PL: Poland, PT: Portugal. RO: Romania. SI: Slovenia. SK: Slovakia. FI: Finland, SE: Sweden

[5] We use the base model estimations from Yigini and Panagos (2016) from 2013 because we lack data on SOC stocks for a later year as we had for 2018.

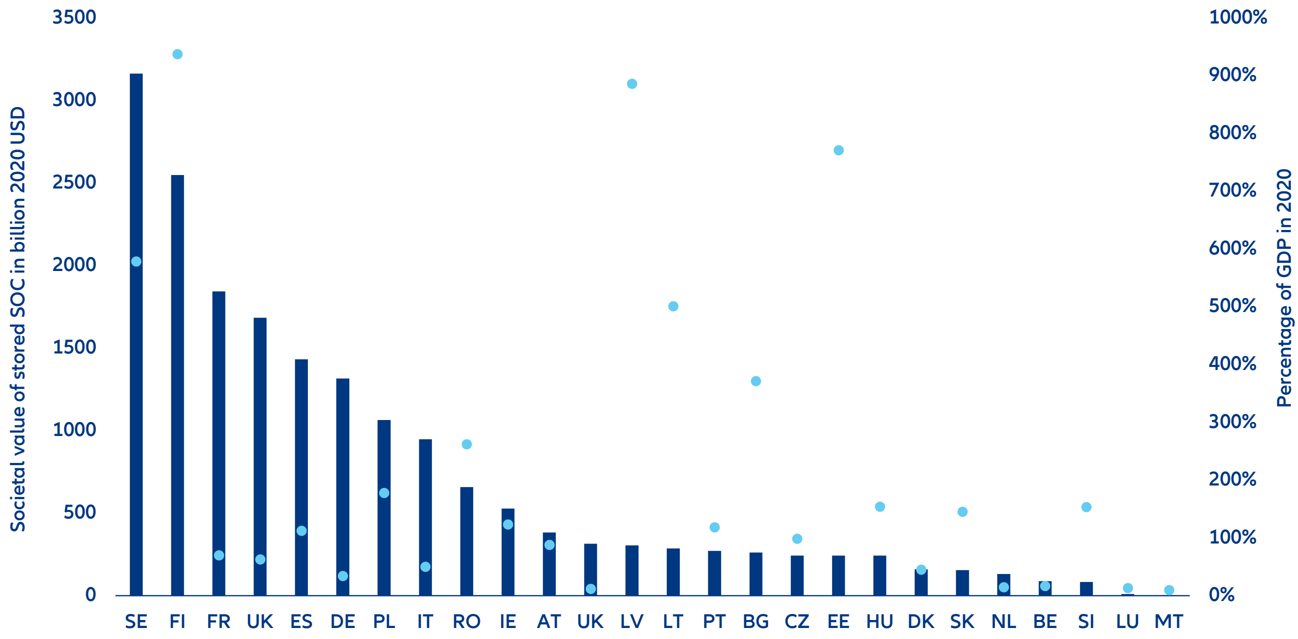
[6] While biodiversity offsets could be imagined for various biodiversity related issues, they are currently dominantly associated with nature based carbon offsets. These do often provide further environmental, social or economic co-benefits.

From an opportunity perspective, the estimates also highlight the social benefits associated with enhancing SOC levels, thereby reducing carbon emissions. Implementing carbon pricing through biodiversity offsets[6] could play a crucial role in financing activities aimed at improving soil quality. Carbon pricing directly addresses transition risk by making the environmental costs of pollution explicit on the balance sheets of polluting companies, thereby challenging business models that rely on societal exploitation and environmental degradation. Although transition risks associated with carbon pricing are well recognized in the context of climate change, the term 'transition opportunities' might be more suitable when discussing biodiversity improvements. This is because financial mechanisms such as biodiversity offsets generate additional revenue streams that support environmentally positive business models.

To ascertain the socioeconomic value of SOC loss, we employ the conservative estimates from the COACCH project (2021), which places the global social cost of carbon at USD132 per ton of CO2 equivalent. This social cost of carbon is equal to the total value of climate damage, which will cause an additional ton of CO2 from 2020 to 2120. This figure represents the average damages caused by an additional ton of CO2 emissions, such as those incurred from extreme weather events. Typically, these costs are not borne by the emitter in the absence of carbon pricing, nor do nature-based activities that sequester carbon receive corresponding benefits without biodiversity offsets. We calculate the monetized value of SOC loss by multiplying the social cost of carbon by the lost SOC stocks for each scenario, assuming a direct conversion rate where one ton of SOC equals 3.664[7] tons of CO2-equivalent. This calculation presupposes that all non-sequestered carbon is released into the atmosphere.

EU countries hold 37.94 petagrams of SOC in the top layer (0-20 cm depth) of soil (Yigini & Panagos, 2016), translating to 139 petagrams (37.94Pg*3.664) of CO2, about three and a half years of current CO2 emissions, about 50% of the remaining CO2 budget to stay within 1.5°C of global warming or a socioeconomic value of approximately USD18.3trn (through the greenhouse-gas emission channel. This value represents about 18% of the global and 1.1 times the European GDP[8] At the national level, the socioeconomic value of SOC stock ranges from around USD26bn in Malta to USD 3.2trn in Sweden.

**Figure 2:** Socioeconomic value of SOC stock in Europe by countries in 2020 USD prices




Sources: Pamuk et al. (2024), Allianz Research.

Notes to the Figure: BE: Belgium, BG: Bulgaria, CZ: Czechia. DK: Denmark, DE: Germany, EE: Estonia, IE: Ireland, EL: Greece, ES:Spain. FR: France. HR: Croatia. IT: Italy. CY: Cyprus LV: Latvia, LT: Lithuania, LU: Luxembourg, HU: Hungary, MT: Malta, NL: Netherlands, AT: Austria, PL: Poland, PT: Portugal. RO: Romania. SI: Slovenia. SK: Slovakia. FI: Finland, SE: Sweden. The bars show the average level of SOC by country.

[7] The ratio between the molecular mass of CO2 and the atomic mass of C is 44.1/12.011= 3.664

[8] This is rather on the lower end of potential estimates, as the social cost of carbon will increase with higher CO2 concenttrations in the atmosphere. Keeping the social cost of carbon constant for the calculation omits the emission trajectory we are on, to which emissons from decreasing SOC levels would contribute as well. We utilize the social cost or carbon estimate from COACCH study for 2020 as 22% of the global GDP and 1.2 times the European GDP, based on the GDP numbers for 2020 or as. 18% of the global GDP and 1.1 times the European GDP, based on the GDP numbers for 2022.

# Abatement measures to preserve soil quality

This study examines a total of five soil-improvement measures – three crop-management practices and two broader land-restoration techniques – that can enhance soil quality. The crop-management practices include no-tillage, cover cropping, and the use of green manure, while the broader land-restoration techniques and measures include agroforestry and sustainable forest management[9]. All these measures contribute to preventing soil erosion, enhancing carbon sequestration, and improving biodiversity (Henry et al., 2022; Dias Rodriguez et al., 2023).

**Table 1:** Key parameters for country cost-benefit analysis for measures to abate soil quality loss[10]

| Measure | A country that the estimate is based on | Indicative cost (USD, 2023) per hectare year, $C_{p(c)}$ | Potential area measure can be applied, hectare, $AR_c$ (1000 ha) | Predicted adoption rate change between 2023-2035 (%) | Assumed annual increase in the adoption rate between 2023-2035, $\Delta AD_p$[11] |
|---|---|---|---|---|---|
| Cover cropping | DE | 178 | 11862 | 45 | 3.8 |
| | NL | 178 | 1042 | 45 | 3.8 |
| | IT | 178 | 9260 | 45 | 3.8 |
| | FR | 178 | 18971 | 45 | 3.8 |
| | UK | 178 | 6024 | 45 | 3.8 |
| | ES | 178 | 16610 | 45 | 3.8 |
| No-tillage | DE | 60 | 11862 | 30 | 2.5 |
| | NL | 60 | 1042 | 30 | 2.5 |
| | IT | 60 | 9260 | 30 | 2.5 |
| | FR | 60 | 18971 | 30 | 2.5 |
| | UK | 60 | 6024 | 30 | 2.5 |
| | ES | 60 | 16610 | 30 | 2.5 |
| Green manures | DE | 209 | 11862 | 25 | 2.1 |
| | NL | 209 | 1042 | 25 | 2.1 |
| | IT | 209 | 9260 | 25 | 2.1 |
| | FR | 209 | 18971 | 25 | 2.1 |
| | UK | 209 | 6024 | 25 | 2.1 |
| | ES | 209 | 16610 | 25 | 2.1 |
| Agroforestry | DE | 436 | 23281 | 10 | 0.8 |
| | NL | 444 | 1412 | 10 | 0.8 |
| | IT | 404 | 18880 | 10 | 0.8 |
| | FR | 420 | 36307 | 10 | 0.8 |
| | UK | 419 | 9222 | 10 | 0.8 |
| | ES | 405 | 35186 | 10 | 0.8 |
| Forest management | DE | 94 | 11419 | 40 | 3.3 |
| | NL | 95 | 370 | 40 | 3.3 |
| | IT | 87 | 9620 | 40 | 3.3 |
| | FR | 90 | 17336 | 40 | 3.3 |
| | UK | 90 | 3199 | 40 | 3.3 |
| | ES | 87 | 18576 | 40 | 3.3 |

Sources: Pamuk et al. (2024), Allianz Research.

Notes to the Table: The sources of indicative costs are as follows: cover cropping, Smit et al., 2019; no-tillage, De Wolf et al. (2019); green manures, KWIN AGV (2018); Agroforestry and forest management (Verhoeven et al., 2023). Estimates can include the costs of yield reduction and the investment required to implement the method (i.e., machinery and labour). In the case of agroforestry and forest management, indicative costs

[9] In forest management, we look at only the benefit of preventing wildfires through prescribed fires once in life-time (100 years), while in our analysis we consider the cost of all other practices covered under sustainable forest management. Those other practices may have also other effects on soil organic carbon levels.

[10] These indicative costs were adjusted for inflation using the growth rate of GDP deflators for Q1 of 2021-2023 for no-tillage and green manures, and for Q1 of 2019-2023 for cover cropping. Source: European Central Bank MNA.Q.N.I9.W2.S1.S1.B.B1GQ._Z._Z._Z.IX.D.N | ECB Data Portal (europa.eu)

[11] Annual adoption rates were calculated using the predicted increase in the assumption rates by experts and in literature for 2023-2035 and dividing those 12.

The cost-benefit analysis for each measure and country is summarized in Table 1, with a detailed methodology and assumptions provided in Appendix 1 for estimating the costs. Research indicates that implementing these measures can significantly increase SOC stocks – no-tillage cover cropping by 37.4% in 11 years, green manure by 34% in five years, and forest management by 21% (Table 2). However, combining measures such as no-tillage and cover cropping can lead to complex interactions such as increased microbial activity, while enhancing soil quality overall, may also elevate soil respiration and thus CO2 emissions, potentially offsetting some carbon storage benefits.

The aggregated costs of implementation for six countries are presented in Figure 3. The measures vary significantly in terms of the land area they can cover, which is directly influenced by their implementation costs. Particularly, this illustrates the implementation costs of these soil quality improvement measures in 2023 prices per hectare for an additional 1,000 hectares in Germany, the Netherlands, Italy, France, the UK, and Spain. The areas calculated for implementation include cropland for no-tillage, cover cropping, and organic manure, and a combination of cropland and forest area for agroforestry; forest management costs are calculated exclusively for forest areas across these countries.

When only the cost of implementation is taken into account, no-tillage emerges as the most economical option, costing less than USD100 per hectare, allowing it to cover the largest area. Conversely, agroforestry, the most expensive measure at over USD400 per hectare, covers the smallest area. It is important to note that the actual implementation of these measures is influenced not only by the costs but also by the willingness of farmers and forest owners to adopt new practices. Additionally, the availability of incentives plays a crucial role in facilitating the transition to these sustainable practices.

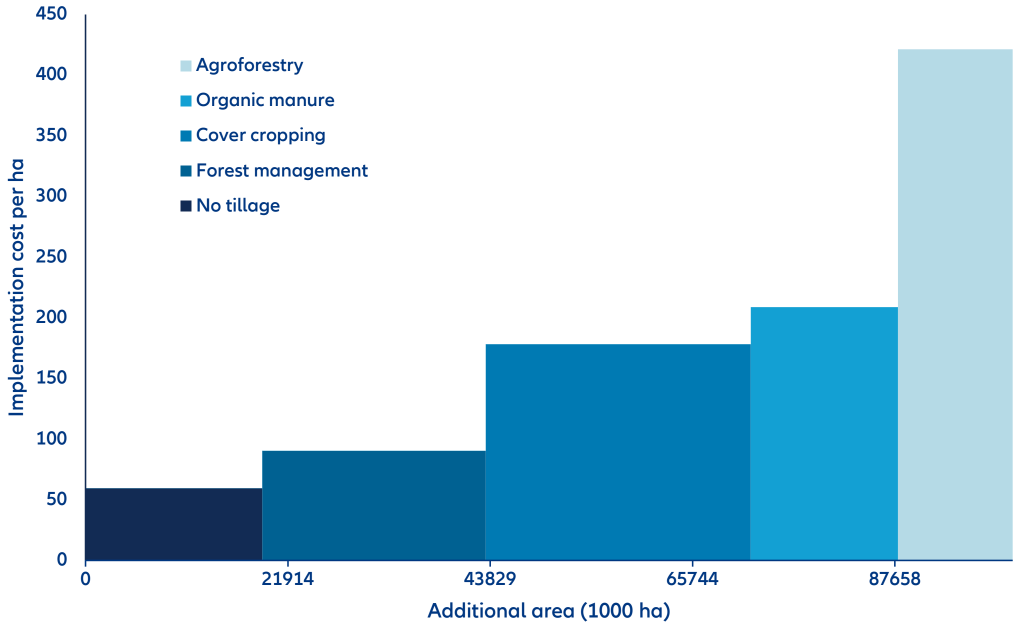
**Table 2:** Reported SOC increases by each measure

| Measure | % change in SOC compared to control groups or baseline | In how many yearshas the change been observed? | Avoided SOC loss (%) | Source |
|---|---|---|---|---|
| Cover cropping | 7.7 | 5 | n.a. | (Joshi et al., 2022) |
| No-tillage | 37.4 | 11 | n.a. | (Wang et al., 2020) |
| Green manure | 34 | 5 | n.a. | (Gross & Glasser, 2021) |
| Agroforestry | 17.8 | 10 | n.a. | (Chatterjee et al., 2018) |
| Forest management | n.a. | n.a | 21 | (Nave et al., 2011) |

Sources: Pamuk at al. (2024), Allianz Research.

Note: Due to availability, they are offered in some cases for the top soil layer of 0-20cm and other times for the 0-30cm or 0-40cm layer. ** Duration of the original studies also varied, so average percentage change per year is used to present the data in a uniform way. N.a.: not applicable. For forest management practice , we assume that this practice eliminates a wildfire once in a lifetime through prescribed fires.

**Figure 3:** Marginal biodiversity loss abatement opportunity curve for soil quality improvements




Sources: WUR, Allianz Research.

Notes: Soil quality improvement measure implementation costs (US$ per hectare in 2023 prices) for covering an additional area (1000 hectares) in Germany, the Netherlands, Italy, France, the United Kingdom, and Spain combined.

*cropland for no-tillage, cover cropping, and organic manure; cropland & forest area for agroforestry; forest area for sustainable forest management across countries were calculated for the implementation cost per ha for agroforestry and forest management. ***Costs are expressed in millions of USD in 2023.

Assuming a direct relationship between carbon in the soil and its emission to the atmosphere via soil respiration, any increase in SOC stocks effectively prevents equivalent carbon emissions. Specifically, we calculate socioeconomic benefits created between 2023 – 2120 by the additional land area the measures can potentially cover each year in selected countries by using the following formula:

$$\mathcal{B}_{mc} = SOC_c \times \mathcal{L}_{mc} \times I_m \times SCC$$

where $\mathcal{B}_m$ is the estimated benefit per measure per country, $SOC_c$ is the CO2 equivalent of the initial SOC stock per country, $\mathcal{L}_{mc}$ is the fraction of land where the measure can be implemented[12], $I_m$ is the estimated impact of the measure[13] and $SCC$ is the social cost of carbon for the period of 2023-2120 that determines the price of carbon[14]. We also incorporated the EU-ETS market carbon auction price of USD87 as of 29 December 2023 for additional validation.

The benefits of these measures must be weighed against their implementation costs between 2023-2120. Table 3a reports the decomposition of the USD32.7bn estimated lifetime cost of implementing abatement measures. We specifically report the results for the additional area covered by those measures each year (for instance, from 2023 to 2024, please see the annual adoption rate in column 6 of Table 1). The costs vary significantly – from USD 13mn for forest management in the Netherlands to USD 4.1for cover cropping in France. These variations are due to factors such as the size of land available, expected adoption rates and per-hectare costs of implementation from 2023 to 2035.

[12] $\mathcal{L}_m$ equals to potential area a measure can be applied, hectare, $\mathcal{AR}_e$ divided by total land size of a country.

[13] To calculate $I_m$, we multiply the annual change in the usage rate of a certain measure (column 6 of Table 1) with the resulting increases in SOC stocks from implementing the practices (column 2 of Table 2). We assume that the measures were applied continuously between 2023 and 2120 and that $SOC$ stocks increased by the maximum percentage change indicated in column 2 of Table 2 during this period.

[14] The SCC is estimated for a period of 100 years. We therefore estimate the total present cost of implementing the abatement measures for almost 100 years continuously. For this purpose, we use a time preference (discount) factor of 3%, the same factor used by the COACCH study to calculate the value of $SCC$. We inflate SCC to 2023 prices, (to US$ 148) using the USD GDP deflator as our cost estimates are in 2023 prices.

**Table 3a:** Decomposition of USD32.7bn estimated lifetime cost of implementing abatement measures on the additional area covered by those measures each year, USD mn (in 2023 prices)

| Measure | France | Germany | Italy | Netherlands | Spain | UK |
|---|---|---|---|---|---|---|
| Agroforestry | 1404 | 934 | 702 | 58 | 1313 | 356 |
| Cover cropping | 4111 | 2571 | 2007 | 225 | 3600 | 1305 |
| Forest management | 575 | 393 | 307 | 13 | 595 | 106 |
| No tillage | 918 | 574 | 448 | 50 | 803 | 291 |
| Green manure | 2676 | 1673 | 1306 | 147 | 2343 | 850 |

Sources: Pamuk et al. (2024), Allianz Research.

Notes to Table: The table shows the total present cost of soil quality loss abatement measure calculated by aggregating AC_mc until 2120 and assuming the additional area that the measure covers in Europe as of 2023 remains covered by the same measure until 2120. AC_mc is the annual investment required for the additional area covered by a measure at each country (please see details in the Appendix). We use a yearly discount factor of 3%, same with COACCH study.

**Table 3b:** Estimated life-time CO2 sequestration by the additional area covered by the abatement measures each year, megatonnes (mt)

| Measure | France | Germany | Italy | Netherlands | Spain | UK |
|---|---|---|---|---|---|---|
| Agroforestry | 13.7 | 9.8 | 6.8 | 0.6 | 11.3 | 7.2 |
| Cover cropping | 14 | 9.8 | 6.5 | 0.9 | 10.4 | 9.2 |
| Forest management | 30.9 | 22.8 | 16.4 | 0.8 | 28.2 | 11.8 |
| No tillage | 45.2 | 31.6 | 21 | 2.9 | 33.7 | 29.7 |
| Green manure | 34.3 | 24 | 15.9 | 2.2 | 25.5 | 22.5 |

Sources: WUR, Allianz Research.

Notes to the Table: The table shows megatonnes of C02 (megatonness sequestered by the abatement measures, which is estimated by using $SOC_c \times L_{mc} \times I_{m.}$

**Table 3c:** Estimated life-time economic benefits between 2023-2120 of the additional area covered by the abatement measures each year, USD mn, 2023 prices

| Measure | France | Germany | Italy | Netherlands | Spain | UK |
|---|---|---|---|---|---|---|
| Agroforestry | 2026.4 | 1453.8 | 1003.7 | 90.9 | 1671.7 | 1064.1 |
| Cover cropping | 2066.8 | 1445.9 | 961 | 130.84 | 1540.4 | 1356.7 |
| Forest management | 4579 | 3374.4 | 2420.3 | 112.8 | 4176.7 | 1746.5 |
| No tillage | 6692.7 | 4682.1 | 3111.9 | 423.7 | 4988.2 | 4393.1 |
| Green manure | 5070.3 | 3547.1 | 2357.5 | 321 | 3779 | 3328.1 |

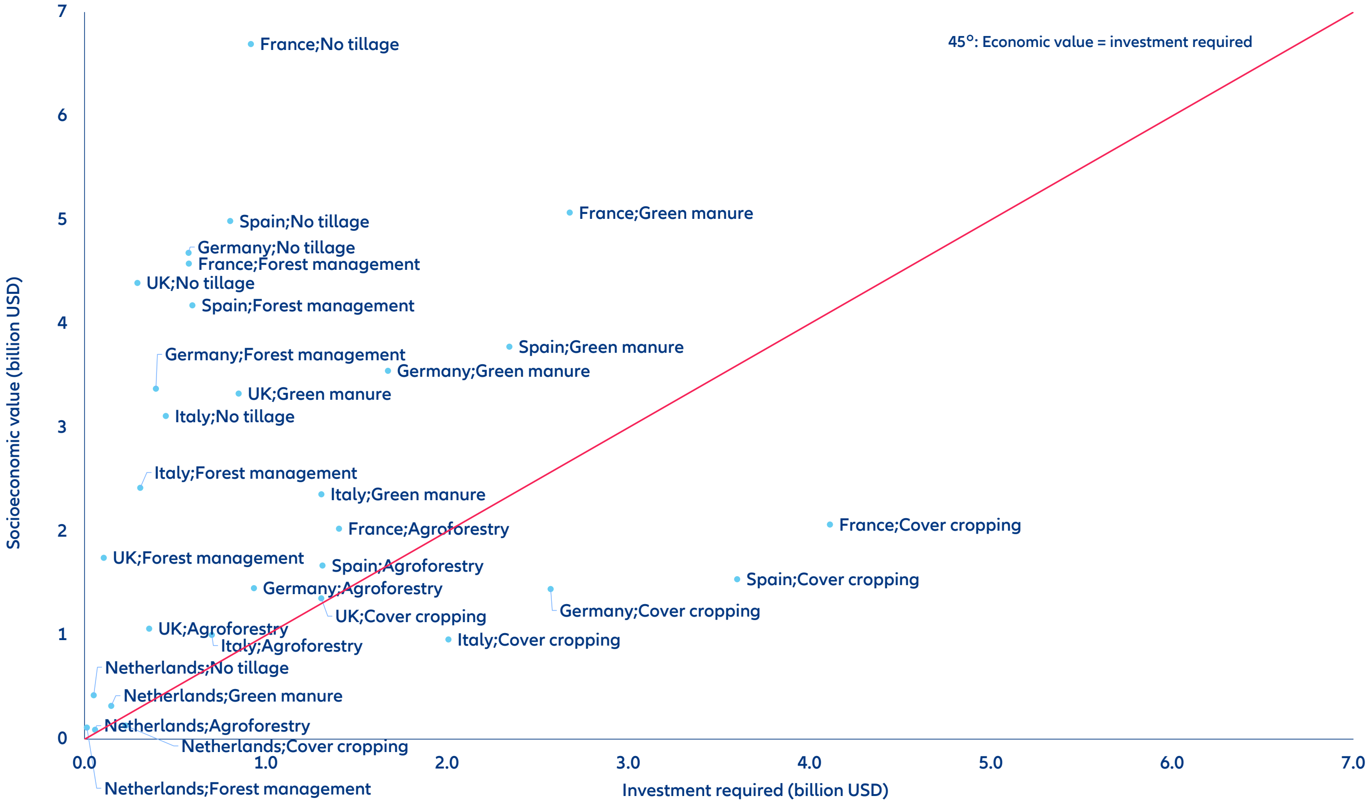
Sources: WUR, Allianz Research.

Notes: The table shows the abatement measures economic benefits' present value for the additional area they cover in Germany, the Netherlands, the UK, Italy, France and Spain each year, using the following formulation.

Our analysis reveals that selected crop-management and land-restoration measures except cover cropping are economically viable due to their potential to sequester carbon, as shown in Figure 4. Practices on the left side of the green line represent 'no regret' options, where the costs of implementation are lower than the economic value of the sequestered GHG emissions, not accounting for additional co-benefits. Specifically, forest management and no-tillage demonstrate high socioeconomic values relative to their costs. Agroforestry shows a balance between the cost of implementation and the generated socioeconomic value, while the investments required for cover cropping are more than the economic benefits through carbon sequestration.

When substituting SCC with lower EU-ETS prices [15](Figure 5), the analysis still supports the economic feasibility of these measures, except for agroforestry. This finding underscores the potential for these practices to be marketed as carbon offsets, demonstrating soil's crucial role in carbon sequestration and presenting a transition opportunity for the financial sector.

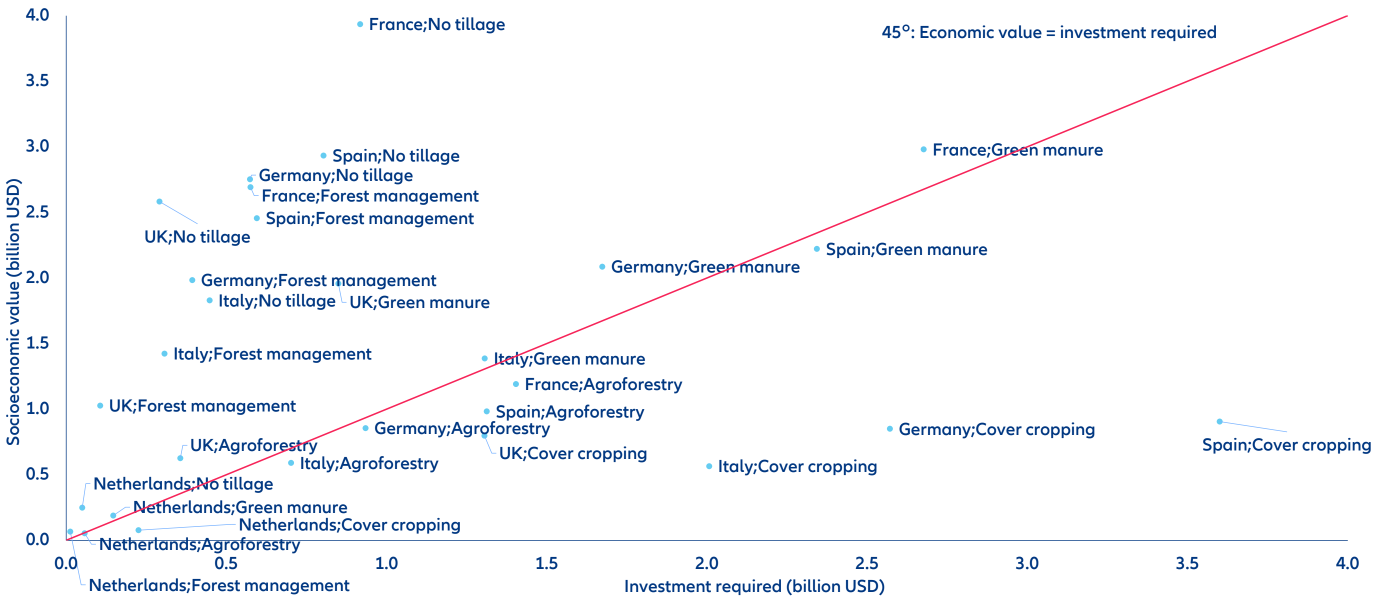
**Figure 4:** Comparison of investment required and socioeconomic value of soil quality from GHG emissions sequestered using social cost of carbon estimate




Source: Pamuk et al. (2024), Allianz Research.
Note: Social economic value numbers are from Table 3c and investment required values are Table 3a.

[15] EU-ETS market carbon auction prices from December 29, 2023.

**Figure 5:** Comparison of investment required and socioeconomic value of soil quality from GHG emissions sequestered using EU-ETS prices at the end of 2023




Sources: Pamuk et al. (2024), Allianz Research.

# Appendix 1: Calculating the cost of abatement measures

The following formulation is used for the calculation:

$$AC_{mc} = C_{m(c)} \times AR_c \times \Delta AD_m$$

$m$ indicates the measure, and $c$ shows the country. $AC_{mc}$ is the annual investment required for the additional area covered by a measure at each country annually. $C_{m(c)}$ is the indicative cost of implementing the practice per hectare per year (column 3 of Table 1). $AR_c$ is the total area (in hectares) of land the measure can potentially be applied in a country (column 4 of Table 1) and $\Delta AD_m$ is the predicted annual change in the usage rate of each measure during the course of 2023 to 2035[16] (column 6 of Table 1). Then $\Delta AD_p$ shows the additional area covered by a measure at each country annually.

We compare $B_{mc}$ with the present value of total investment required for continuously using the measures until 2120 after adoption it once. To do this, we estimate the present value of $AC_{mc}$ in for each year (e.g., 2023, 2024, 2025,...) until 2120 and aggregate it using a yearly discount factor of 3%. This discount factor is same with the discount factor used by the COACHH study. The social cost of carbon estimate that we use from the COACHH study also considers the total economic value of carbon sequestration generates between 2023 and 2120.

For no-tillage and use of green manures, estimates of $AR_c$ and $\Delta AD_m$ are from Pamuk et al., 2023. For cover cropping, we follow the literature suggesting that $\Delta AD_p$ and $AR_c$ for cover cropping should be similar to the adoption rates for biocontrol measures (Smit et al., 2021). We, therefore, assumed that the predicted adoption rates for biocontrol measures from Pamuk et al. (2023) should also be the same for cover cropping and used those estimates.

For sustainable forest management, the current forest under management and the EU forest strategy states that 60% of the forests are currently under management, and it stresses that 100% of forests should be under management by 2030 (European Commission, 2021). Following this, we assume that forest land under sustainable forest management may increase by 40pps compared to 2023. For agroforestry, we estimated the change in crop and forest land covered by agroforestry from 2023 to 2035, ($\Delta AD_p$), using existing trends highlighted in the literature. Rubio-Delgado et al. (2023) used LUCAS soil data for the period of 2009-2018 and reported that the adoption of different agroforestry practices has varying trends: they have been increasing and decreasing in different subperiods of the time frame that the study covers. Here, we picked a best-case scenario: kitchen gardens, an agroforestry system that had a net increase of 7% in 10 years and across countries. We consider this number in the light of recent EU policies such as the CAP or EU carbon farming that increasingly motivate the implementation of agroforestry systems and assume that agroforestry adoption will increase by 10% in the period of 2023-2035 in a 13-year period. The area for implementation of agroforestry ($AR_c$) includes both cropland and forest areas for each country since some agroforestry systems can be implemented in agricultural settings as well as to restore degraded forests. For sustainable forest management, an area covering forest land per country ($AR_c$) is used as a potential area to implement this measure.

Indicative costs $C_{p(c)}$ for crop management measures are based on a study compiling costs for only one country, the Netherlands (Smit et al., 2019; Smit et al., 2021). The costs for land restoration are model estimates from Verhoeven et al., (2023) and they are country specific.

[16] Due to budget and time limitations to perform the analysis, these adoption rates are not crop specific. Future studies could explore adoption rates of each measure for different crops and countries.

# Appendix 2: References

Beillouin, D., Corbeels, M., Demenois, J., Berre, D., Boyer, A., Fallot, A., ... & Cardinael, R. (2023). A global meta-analysis of soil organic carbon in the Anthropocene. Nature Communications, 14(1), 3700.

Berhe, A.A. et al. (2018). 'Role of Soil Erosion in Biogeochemical Cycling of Essential Elements: Carbon, Nitrogen, and Phosphorus', https://doi.org/10.1146/annurev-earth-082517-010018, 46, pp. 521–548. Available at: https://doi.org/10.1146/ANNUREV-EARTH-082517-010018.

Berryman, E. et al. (2020). 'Soil Carbon', Forest and Rangeland Soils of the United States under Changing Conditions: A Comprehensive Science Synthesis, pp. 9–31. Available at: https://doi.org/10.1007/978-3-030-45216-2_2/TABLES/2.

Borrelli, P. et al. (2020). 'Land use and climate change impacts on global soil erosion by water (2015-2070)', Proceedings of the National Academy of Sciences of the United States of America, 117(36), pp. 21994–22001. Available at: https://doi.org/10.1073/pnas.2001403117.

Bronick, C.J. and Lal, R. (2005) 'Soil structure and management: a review', Geoderma, 124(1–2), pp. 3–22. Available at: https://doi.org/10.1016/J.GEODERMA.2004.03.005.

Bünemann, E.K. et al. (2016) Report number: 04 Deliverable: D3.1 Report type: Report Concepts and indicators of soil quality-a review. Available at: www.isqaper-project.eu.

Carter, M.R. et al. (1997) 'Chapter 1: Concepts of soil quality and their significance', Developments in Soild Science, 25, pp. 1–19.

Doetterl, S. et al. (2016) 'Erosion, deposition and soil carbon: A review of process-level controls, experimental tools and models to address C cycling in dynamic landscapes', Earth-Science Reviews, 154, pp. 102–122. Available at: https://doi.org/10.1016/J.EARSCIREV.2015.12.005.

ENCORE (2023) Exploring Natural Capital Opportunities, Risks and Exposure, Exploring Natural Capital Opportunities, Risks and Exposure.

European Commission (2010) The factory of life. Why soil biodiversity is so important, Directorate-General Environment. Available at: https://doi.org/10.2307/j.ctt1zxsjv1.7.

FAO (2015a) Healthy soils are the basis for healthy food production, FAO in Action. Rome. Available at: http://www.fao.org/3/a-i4405e.pdf.

FAO (2015b) Soils help to combat and adapt to climate change, FAO in Action. Rome. Available at: http://www.fao.org/3/a-bb018e.pdf.

FAO (2015c) Soils store and filter water. Rome.

FAO (2021) The State of the world's Land and Water Resources for Food and Agriculture – Systems at breaking point. Synthesis report 2021, The State of the World's Land and Water Resources for Food and Agriculture – Systems at breaking point (SOLAW 2021). Rome: FAO. Available at: https://doi.org/10.4060/cb7654en.

FAO (2022) Soils for nutrition: state of the art, Food and Agriculture Organization of the United Nations. Rome. Available at: https://doi.org/10.4060/cc0900en.

FAO and ITPS (2015) Status of the World's Soil Resources (SWSR) – Main Report.

Fernandes Ugalde, O. et al. (2022) LUCAS 2018 Soil module. Luxembourg: Publications Office of the European Union. Available at: https://doi.org/10.2760/215013.

Ji, L., Xin, Y., & Guo, D. (2023). Soil Fungal Community Structure and Its Effect on CO2 Emissions in the Yellow River Delta. International Journal of Environmental Research and Public Health, 20(5), 4190.

Kirkels, F.M.S.A., Cammeraat, L.H. and Kuhn, N.J. (2014) 'The fate of soil organic carbon upon erosion, transport and deposition in agricultural landscapes — A review of different concepts', Geomorphology, 226, pp. 94–105. Available at: https://doi.org/10.1016/J.GEOMORPH.2014.07.023.

Li, T. et al. (2019) 'Soil erosion affects variations of soil organic carbon and soil respiration along a slope in Northeast China', Ecological Processes, 8(1), pp. 1–10. Available at: https://doi.org/10.1186/S13717-019-0184-6/FIGURES/6.

Lin, H. et al. (2022) 'Simulating the effects of erosion on organic carbon dynamics in agricultural soils', Catena, 208(September 2021), p. 105753. Available at: https://doi.org/10.1016/j.catena.2021.105753.

Ma, Y. et al. (2023) 'Global crop production increase by soil organic carbon', Nature Geoscience, 16(12), pp. 1159–1165. Available at: https://doi.org/10.1038/s41561-023-01302-3.

Maes, J. et al. (2020) Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment. EUR 30161 EN, Publications Office of the European Union, Ispra, 2020, ISBN. Available at: https://doi.org/10.2760/757183.

Muñoz-Rojas, M., Pereira, P. and Martínez-Murillo, J.F. (2018) 'Soil quality indicators: critical tools in ecosystem restoration This review comes from a themed issue on Sustainable soil management and land restoration'. Available at: https://doi.org/10.1016/j.coesh.2018.04.007.

Nortcliff, S. (2002) 'Standardisation of soil quality attributes', Agriculture, Ecosystems and Environment, 88(2), pp. 161–168. Available at: https://doi.org/10.1016/S0167-8809(01)00253-5.

Nunes, F.C. et al. (2020) 'Soil as a complex ecological system for meeting food and nutritional security,' Climate Change and Soil Interactions, pp. 229–269. Available at: https://doi.org/10.1016/B978-0-12-818032-7.00009-6.

Oldfield, E. E., Bradford, M. A., & Wood, S. A. (2019). Global meta-analysis of the relationship between soil organic matter and crop yields. Soil, 5(1), 15-32.

Pamuk, H., Arredondo Rivera, M., Nannes, J., van Zeist, W.-J., & Polman, N. (2023). Bending the curve for biodiversity loss and economy: case study evidence from pollination services loss. (Report / Wageningen Economic Research; No. 2023-081). Wageningen Economic Research. https://doi.org/10.18174/634599

Pamuk, H., Arredondo Rivera, M., Nannes, J., van Zeist, W.-J., Naranjo Barrantes, M., & Polman, N. (2023). (2024) A step to estimate the value of ecosystem services provided by soil: Case study evidence from soil quality (forthcoming as WUR publication)

Panagos, P. et al. (2018) 'Cost of agricultural productivity loss due to soil erosion in the European Union: From direct cost evaluation approaches to the use of macroeconomic models', Land Degradation and Development, 29(3), pp. 471–484. Available at: https://doi.org/10.1002/ldr.2879.

Paul, C. et al. (2023) 'Carbon farming: Are soil carbon certificates a suitable tool for climate change mitigation?', Journal of Environmental Management, 330(December 2022). Available at: https://doi.org/10.1016/j.jenvman.2022.117142.

Pravalie, R. et al. (2021) 'Global changes in soil organic carbon and implications for land degradation neutrality and climate stability', Environmental Research, 201, p. 111580. Available at: https://doi.org/10.1016/j.envres.2021.111580.

Poeplau, C., & Dechow, R. (2023). The legacy of one hundred years of climate change for organic carbon stocks in global agricultural topsoils. Scientific Reports, 13(1), 7483.

Svartzman, R. et al. (2021) A 'Silent Spring' for the Financial System? Exploring Biodiversity-Related Financial Risks in France, Banque de France. Available at: https://doi.org/10.2139/ssrn.4028442.

UNCCD (2022a) Second Edition Land Restoration for Recovery and Resilience.

UNCCD (2022b) Summary for Decision Makers. Global Land Outlook. second edi. Bonn: United Nations Convention to Combat Desertification.

Wang, M., Guo, X., Zhang, S. et al. Global soil profiles indicate depth-dependent soil carbon losses under a warmer climate. Nat Commun 13, 5514 (2022). https://doi.org/10.1038/s41467-022-33278-w

Woltjer, G. and Kuiper, M. (2014) 'The MAGNET model: Module description', Wageningen UR., p. 144. Available at: www.wageningenUR.nl/en/lei.

Wuepper, D., Borrelli, P. & Finger, R. Countries and the global rate of soil erosion. Nat Sustain 3, 51–55 (2020). https://doi.org/10.1038/s41893-019-0438-4

WWF (2023) What is Erosion? Effects of Soil Erosion and Land Degradation. Available at: https://www.worldwildlife.org/threats/soil-erosion-and-degradation (Accessed: 10 December 2023).

Yigini, Y. and Panagos, P. (2016) 'Assessment of soil organic carbon stocks under future climate and land cover changes in Europe', Science of The Total Environment, 557–558, pp. 838–850. Available at: https://doi.org/10.1016/J.SCITOTENV.2016.03.085.

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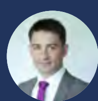

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