Carbon sequestration in soils: What can we achieve in European agricultural soils?

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- Management options that increase soil carbon are key to soil health and climate change mitigation
- It is possible to avoid 20-30 % of current European agricultural greenhouse gas emissions (including LULUCF), by optimizing agricultural management towards increased carbon accrual in soils (0-50 cm).
- Agroforestry and biochar have the largest potential in potentially sequestering carbon

Introduction

Increasing soil carbon can contribute to climate change mitigation. EJP SOIL quantified the potential of additional carbon storage in agricultural mineral soils of Europe.

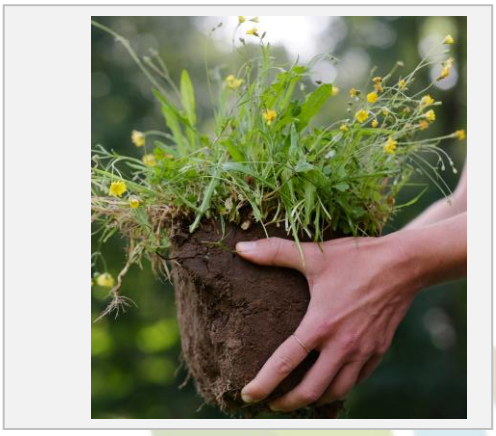
The carbon farming strategy of the European Commission heavily relies on the accrual of carbon through the build-up of soil organic carbon (Regulation (EU) 2023/839, Regulation (EU) 2024/3012). This process removes carbon dioxide from the atmosphere. Thus, it can support climate change mitigation.

But how large is the feasible potential of agricultural soils to accrue more carbon? Which management options have the largest potential? And where in Europe can these be newly implemented? These are key questions that must be addressed to ensure the success of the carbon farming strategy.

Scientists from the EJP SOIL programme in the CarboSeq project conducted studies spanning all across Europe to address these questions. And they have news to share: by adjusting agricultural management, emissions corresponding to 20-30 % of current European agricultural greenhouse gas emissions (including the LULUCF sector) could be avoided. All investigated management options for building up organic carbon led to an overall decrease in greenhouse gas emissions.

Description of the Issue

Degraded soils threaten agricultural productivity and fuel the climate crisis by emitting greenhouse gases. On the contrary, well-managed agricultural soils, where climate-smart management options are adopted, support critical ecosystem



Picture 1: Plant biomass forms soil organic carbon. It needs to be enhanced and returned to the soil to sequester carbon in soils

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services and soil health – including carbon storage and climate change mitigation.

Currently, soil health is receiving increased political attention through carbon removal and carbon farming initiatives. However, to achieve carbon sequestration through targeted climate-smart soil management, we need to understand which management practices and regions bear the largest potential.

URGENT NEED TO QUANTIFY CARBON SEQUESTRATION POTENTIALS FOR EUROPE

The European Green Deal aims at climate neutrality of the EU by 2050. To realize this, we need additional carbon sinks. The "4 per 1000" Initiative calculated that a theoretical annual increase in global soil carbon stocks by 0.004% could offset all anthropogenic greenhouse gas emissions. This is a theoretical potential illustrating the importance of soil carbon in the global carbon cycle but with no relation to what can realistically be achieved with carbon sequestration in soils.

To estimate a feasible carbon sequestration potential in agriculture, it is critical to know how much and through which agricultural management options carbon could be sequestered in soils. For this, local environmental and agricultural conditions as well as technical constraints need to be considered. Also, already implemented management options and potential trade-offs need to be taken into account. With such a holistic estimate, clear, actionable strategies can be developed for carbon removal in agriculture.

Increasing soil carbon is more than just climate change mitigation. In fact, climate-smart management options have multiple co-benefits on soil functions and thus on the overall soil health (e.g., for biodiversity, soil protection, water and nutrient retention). Soil health is crucial for sustainable agriculture and helps to increase resilience of agriculture to climate change effects. However, the magnitude of co-benefits depends on soil type, climate and farm conditions. Therefore, realistic estimates must consider the local environmental and agricultural conditions.

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KEY MESSAGES FOR POLICY MAKERS

Recommendation One: **Focus on management options that can be implemented on large areas.**

The success of carbon sequestration efforts in European agriculture hinges on scaling up the area where agricultural management options are implemented (Figure 1A). Even if the carbon sequestration per hectare of a measure is low, the impact is high when it is applied on a large area (Figure 1B).

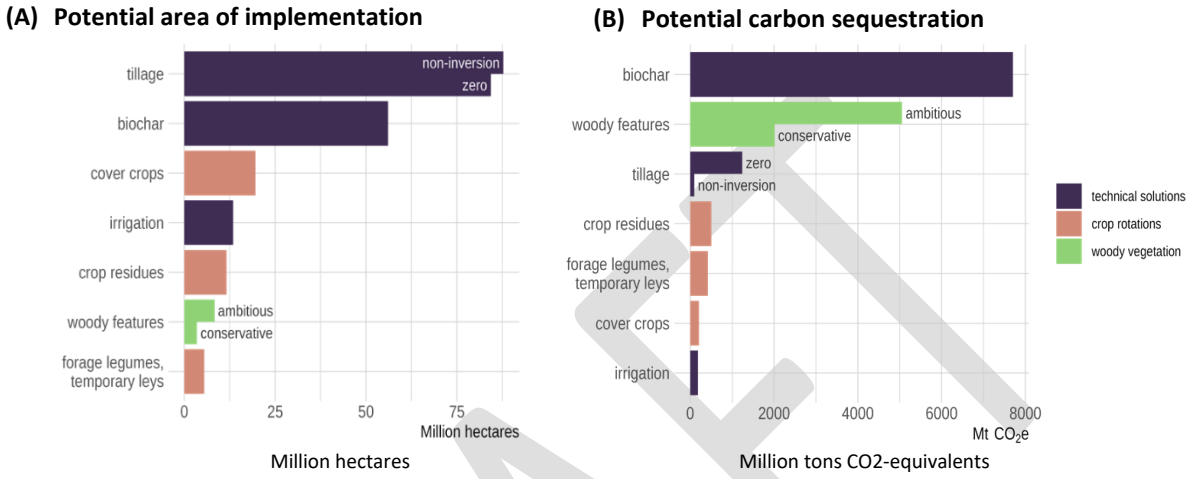

Figure 1: Management option increasing carbon accrual at European scale ranked by (A) total area of implementation and (B) by total carbon sequestration potential.

Recommendation Two: **Support the implementation of agroforestry systems.** Agroforestry with hedges, alley cropping and silvopasture on agricultural land have a large carbon sequestration potential in almost all European countries. In these systems, most additional carbon is stored in the plants biomass. Compared to arable land, agroforestry has multiple co-benefits, such as increased biodiversity and supply of additional woody feedstock.

Recommendation Three: **Biochar has a large potential in European agriculture to retain and stabilise organic carbon in the long-term.** Its potential is limited by the availability of the feedstock in Europe. Instead of burning biomass for heating purposes, biomass should be pyrolysed, creating biochar and heat simultaneously. Costs and biomass availability however are key inhibitors for implementation.

Recommendation Four: **Non-CO_2 greenhouse gas emissions need to be considered in carbon removal calculations and for individual management options.** With N_2O as an example, non-CO_2 greenhouse gas emissions can increase the carbon sequestration potential (in CO_2e) for woody features and biochar by 39 % and 22 % respectively, while the other management options potentials are reduced by 20 % to 70 %.

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SUPPORTING POLICY

European agricultural mineral soils have the potential to mitigate up to 20-30 % of agricultural greenhouse gas emissions (incl. LULUCF) in Europe. Achieving this potential will require strong political will and economic incentives, both of which are crucial to translating potential carbon sequestration into tangible outcomes.

The success of carbon sequestration in agricultural soils depends on scaling up the implementation of proven and standardized agricultural management options. In the CarboSeq project, we only considered such proven options that can effectively contribute to the European Green Deal's goal of achieving climate neutrality by 2050.

METHODOLOGY

The CarboSeq project gathered all available data from around 500 European long-term field experiments measuring the impact of agricultural management options on soil organic carbon to create a database for crop and soil management. From this database, ten agricultural management options have been identified as those are proven to enhance soil organic carbon in mineral soils. We excluded the options from the analysis that resulted in significant reductions in yields, because this would cause a relocation of production to outside of the EU including a shift of resulting greenhouse gas emissions rather than a real reduction. Moreover, we also excluded options that would result in increasing animal stocking rates with concomitant increased greenhouse gas emissions.

The management options were clearly defined and grouped into three categories:

- technical solutions (i.e., non-inversion tillage, zero-tillage, irrigation, biochar application),
- improved crop rotations (i.e., perennial legumes, cover cropping, crop residue management),
- the introduction of woody features on farmland (i.e., hedgerows, alley cropping, silvopasture).

Based on the analysis of the database, emission factors were estimated. These emission factors indicate how much carbon a measure can accrue in the soil per hectare, compared to a business-as-usual scenario. The potential area of implementation has been defined, considering biophysical, technical and political limitations. Additionally, the current level of implementation of the management options was taken into account to determine where additional options can be implemented (Figure 3, hatched area).

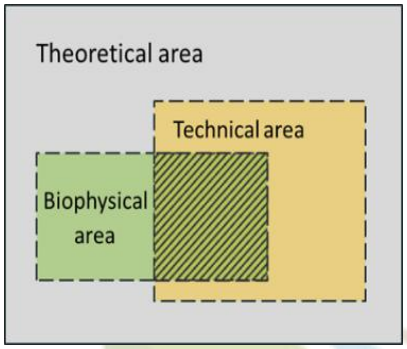

Figure 3: Areas of implementation for management options. The theoretical area is identical for all options, the bio-physical and technical areas of implementation differ among individual options.

Based on these considerations, we calculated the Europe-wide potential for

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additional carbon storage in agricultural mineral soils.

The effect of including subsoil carbon in the calculations has been considered for all management options excluding biochar as this is only applied to topsoil. We calculated the effects of changes in agricultural management on subsoil carbon stocks through a ratio of topsoil (0-30 cm) to subsoil (30-50 cm) for each measure and added it to the respective carbon sequestration potential.

For non-CO_2 greenhouse gases, N_2O emissions were considered for non-inversion tillage, no tillage, cover crops and woody features. For the other agricultural management options, no reliable data was available.

REFERENCES

REGULATION (EU) 2023/839 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, of 19 April 2023, amending Regulation (EU) 2018/841 as regards the scope, simplifying the reporting and compliance rules, and setting out the targets of the Member States for 2030, and Regulation (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review

REGULATION (EU) 2024/3012 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, of 27 November 2024, establishing a Union certification framework for permanent carbon removals, carbon farming and carbon storage in products

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