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Increasing Soil Organic Carbon Stocks through Nature-Based Solutions for Climate Mitigation and Agricultural Sustainability

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1. Abstract

The deprivation in soil organic carbon (SOC) stocks have a major impact on atmospheric carbon accumulation. Enhancing SOC stocks through sustainable agricultural management practices can play a crucial role in climate mitigation. Increasing SOC levels not only improves soil fertility by enhancing its physical and biological properties but also mitigates the adverse effects of agricultural intensification and land-use changes. Nature-based solutions (NBSs) offer an innovative approach to addressing these challenges by promoting carbon sequestration and ecosystem resilience. This article explores the role of NBSs in increasing SOC stocks and their application in the CARBONICA HORIZON project [1].

2. Introduction

Soil is a critical carbon sink, containing three times the amount of carbon present in the atmosphere. It sequesters three times the amount of carbon present in the atmosphere and could potentially remove from the atmosphere 0.79 to 1.54 Gt yr^{-1} of carbon- if land uses and management practices increased C inputs and/or reduced C losses [2]. Moreover, SOC improves soil nutrient availability, cation exchange capacity, water retention capacity, soil aeration, soil aggregation and structure, soil microbial biomass and its activity, crop yield, and crop quality. However, the consistent agricultural intensification and land-use changes, such as converting grasslands into croplands, contribute to SOC depletion. These losses are accelerated by low organic input practices, which promote oxidation, mineralization, leaching, and erosion. Adopting sustainable land management practices can enhance soil quality, boost SOC levels, and contribute to climate mitigation efforts [3].

3. The Role of Nature-Based Solutions in Carbon Sequestration

Nature-based solutions (NBSs) are actions that mimic natural processes to sustainably address land use and management, human health, and biodiversity. By replicating ecosystem functions, NBSs aid in climate change mitigation, disaster risk reduction, water management, and biodiversity conservation. Recognized as impactful for carbon sequestration, NBSs can sequester approximately 10 gigatons of CO2 equivalent annually. These agricultural management practices not only mitigate environmental risks but also provide long-term benefits in food security and climate change resilience and adaptation [4].

4. Nature-Based Solutions for Soil Carbon Sequestration

The Natural Climate Solutions World Atlas identifies 15 key NBS methods [5], including reforestation, grazing management, and ecosystem restoration. Nature-based solutions that better manage agricultural land will often increase productivity at the same time as yielding climate benefits, further contributing to reduced land conversion pressure [6]. In terms of farming practices and their emissions mitigation impact, the European Union estimates that crop rotation or diversification, expansion of cover crops and conversion to organic farming contribute 78% of the estimated mitigation potential [7]. Within the CARBONICA HORIZON project, i-BEC proposes a series of NBSs to support farmers in adopting sustainable agricultural management practices. To expand the reach of NBSs, the CO_2 Solutions Living Lab was created, implementing and assessing NBS strategies across diverse agricultural landscapes. The following is a list of well recognized Nature- Bases Solutions.

Table 1. NBSs for soil carbon sequestration

List of NBS for carbon farming and carbon sequestration			
Group of carbon farming practices	Carbon farming practice	Definitions	Sources
Use of organic amendment	Biochar	Carbon-rich material obtained by plant biomass pyrolysis	[8]
	Anaerobic digestate	Semi-liquid OA with fertilizercharacteristics obtained from anaerobic digestion of plant biomass and/ or animal manure and slurry as by-product of biogas plants	[9]
	Compost	Humus-like material with fertilizer characteristics obtained from aerobic digestion of solid waste	[10]
	Farmyard manure	Decomposed animal feces mixed with stubble with fertilizer characteristics	[11]
Reduced soil disturbance	Minimum tillage	Non-inversion tillage at maximum 15-10 cm depth	[12], [13]
	No till	Sod-seeding	
	Reduced intensity tillage	Reduce number of tillage operation compared to business-as-usual	
	Reduced tillage	Non-inversion tillage atmaximum 25 cm depth	
Cover Crops	Cover crops as green manure	Crops cultivated to obtain plant biomass are incorporated into soil with tillage operations	[14]
	Cover crops as green dead mulch	Crops cultivated to obtain plant biomass which is mowed/ trimmed and left on soil surface as dead mulch	
Agronomic management	Intercropping	The practice of growing two or more crops in a field at the same time	[15]
	Improved crop rotations	Practice of growing different crops in recurrent succession on the same land	[14]
	Conservation agriculture	Agronomic management applying reduced soil disturbance combined with maintenance of crop residues, crop rotations, cover crops, inorganic fertilizer application)	[16]
	Organic agriculture	Organic farming is defined by the Reg. UE 2018/848	[17]
	Crop residues	Maintenance and incorporation of crop residues on field	[18]

5. Implementation in Agricultural Systems

The CO2 Solutions Living Lab operates in five pilot sites spanning five different crops and thirteen demonstration sites. The NBSs applied to the broccoli (Ardas/Orestiada, Eastern Macedonia and Thrace), kiwi (Chryssoupoli, Eastern Macedonia and Thrace), and grapevine (Epanomi, Central Macedonia) cultivations include minimum tillage and crop residue incorporation—already showing positive results in terms of carbon sequestration and reduction of greenhouse gas emissions.

6. Conclusion

Increasing SOC stocks through nature-based solutions presents a promising strategy for climate change mitigation and agricultural sustainability. By implementing sustainable and holistic management practices, soil health can be improved, leading to increased carbon sequestration and agricultural resilience. Projects like CARBONICA HORIZON and initiatives such as the CO2 Solutions Living Lab provide practical frameworks for scaling up NBS adoption, ensuring long-term environmental and economic benefits.

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