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Policy on Integrating Soil Health into Climate and Carbon Market Frameworks: A Pathway to Resilient Food Systems and Verified Carbon Drawdown

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Authors' contributions

This work was carried out in collaboration among all authors. Authors IB, LDS conceptualized and prepared initial draft of manuscript. Authors HLD, SS did literature searches. Authors SKC, ELD and ALJ compiled and edited final of the manuscript. All authors read and approved the final manuscript.

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Policy Article

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ABSTRACT

The climate crisis necessitates urgent and multifaceted strategies for mitigating greenhouse gas (GHG) emissions. While energy transition dominates discourse, the terrestrial biosphere, and agricultural soils in particular, represent a critical and underutilised sink for atmospheric carbon. The study aims to explore how integrating soil health practices into climate and carbon market frameworks can enhance food system resilience while ensuring verified carbon sequestration. This policy paper argues for the systematic integration of soil health principles into national climate policies and international carbon market frameworks. We detail the scientific rationale behind soil carbon sequestration, highlighting its co-benefits for agricultural resilience, water security, and biodiversity. The paper examines the current challenges within voluntary carbon markets (VCMs), including issues related to measurement, monitoring, reporting, and verification (MMRV), permanence, leakage, and additionality. We present a suite of policy recommendations aimed at governments, standard-setting bodies, and private market participants to overcome these barriers. By adopting a "soil-health-first" approach that values ecosystem services beyond carbon, we can unlock a powerful, natural climate solution that supports both planetary health and agricultural livelihoods. Data from key studies accentuate the significant potential, estimating global soil carbon sequestration capacity at 2-5 Gt CO_2e per year. Soil health is not a silver bullet for the climate crisis, but it is a foundational element of any successful strategy to achieve a net-zero future. By adopting the recommendations outlined in this paper, stakeholders can unlock the immense potential of the earth beneath our feet to help stabilise the atmosphere above it. The time to invest in soil health is now.

Keywords: Carbon markets; climate policy; regenerative agriculture; soil carbon sequestration; soil health.

1. INTRODUCTION

Recent assessments by the Intergovernmental Panel on Climate Change (IPCC) underscore that limiting global warming to 1.5°C above pre-industrial levels necessitates both immediate, substantial reductions in greenhouse gas (GHG) emissions and the removal of billions of tons of historical carbon dioxide from the atmosphere (IPCC, 2022). This dual imperative of mitigation and carbon dioxide removal (CDR) has intensified the search for scalable, cost-effective, and environmentally sustainable strategies. Although technological solutions such as direct air capture are progressing, they remain energy-intensive and costly at scale. In this context, enhancing the natural carbon sequestration capacity of global soils has re-emerged as a critical yet underutilised opportunity. Soils constitute the largest terrestrial carbon pool, storing more carbon than the atmosphere and vegetation combined, which positions soil management as a central mechanism in the global carbon cycle (Amundson & Biardeau, 2018). However, soil is a significant carbon sink that contributes to combating global warming by trapping significant quantities of carbon from the atmosphere. However, the role soil carbon sequestration plays in achieving the goals of the global climate emphasises how crucial it is to lower greenhouse gas (GHG) emissions while improving soil health and production (Kumar *et al*., 2025).

Soil organic carbon (SOC) forms the foundation of soil organic matter, regulating key functions such as nutrient cycling, water infiltration and retention, and structural stability. SOC is fundamental to agricultural productivity and ecosystem health. (SOC) holds a key part in the carbon cycle, as at a 1 m depth, soils store about 1500 Gt C, being the largest terrestrial carbon pool. Therefore, carbon sequestration could potentially mitigate climate change, as highlighted by the “4 per 1000 initiative” at the 21st conference of the parties to the United Nations Framework Convention on Climate Change (COP21). An increase of 0.4% per year would be considerably beneficial for the reduction of GHG emissions Angelopoulou *et al*., 2019; Yost & Hartemink, 2019). However, extensive agricultural expansion and prolonged industrial practices, including excessive tillage, monocropping, and heavy reliance on synthetic inputs, have significantly degraded global soils. This degradation has resulted in substantial depletion of SOC stocks, releasing large amounts of CO_2 into the atmosphere and reducing land productivity (Lal, 2004). The resulting carbon debt in global agricultural lands presents a significant opportunity for restoration and serves as a potent natural climate solution. Research indicates that global soils could sequester a considerable portion of annual anthropogenic CO_2 emissions through widespread adoption of improved management practices (Paustian et al., 2016).

This paper contends that integrating soil health into the core of climate policy and carbon finance is not merely an optional add-on but an essential strategy for achieving net-zero emissions and building systemic resilience. We define soil health as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans (Lehmann et al., 2020). This definition moves beyond a simple chemical-input-output model to encompass the biological complexity and physical structure that underpin a soil's functionality. A soil-health-centric approach offers a synergistic pathway that addresses multiple challenges simultaneously: it mitigates climate change by drawing down atmospheric carbon, adapts to its impacts by creating more resilient agroecosystems buffered against drought and deluge, enhances food security by improving yields and reducing input dependency, and safeguards biodiversity by restoring habitat below and above ground (Depietri, 2025).

2. THE RATIONALE FOR SOIL-CENTRIC CLIMATE POLICY

The case for centring soil health in climate action is built on a robust body of scientific evidence and encompasses a wide array of interconnected benefits.

2.1 The Science of Soil Carbon Sequestration

Soil carbon sequestration is the process of transferring CO_2 from the atmosphere into the soil through plant residues and other organic solids, where it is stored as soil organic matter. This process is driven by photosynthesis and managed through agricultural practices (Cerri et al., 2024). Key practices that enhance SOC include:

- **Cover Cropping**: Planting crops like clover or rye during off-seasons to protect soil, add organic matter, and fix nitrogen.
- **Reduced or No-Till Farming:** Minimising soil disturbance to reduce oxidation of SOC and protect soil structure.
- **Diverse Crop Rotations**: Disrupting pest and disease cycles and adding varied biomass to the soil.
- **Integrated Nutrient Management**: Using compost, manure, and biochar to add stable organic matter.
- **Agroforestry and Silvopasture**: Integrating trees and shrubs into cropping and livestock systems.

Research by Paustian et al. (2016) demonstrates that the widespread adoption of these practices could sequester significant amounts of carbon, as shown in Table 1.

2.2 Co-benefits: Beyond Carbon

The value of soil health extends far beyond carbon storage. Investing in SOC delivers a multitude of co-benefits that enhance agricultural sustainability and resilience:

- **Enhanced Food and Water Security**: Increased SOC improves soil water infiltration and retention, reducing vulnerability to drought and flood. It also enhances nutrient cycling, reducing the need for synthetic fertilisers and boosting crop yields over the long term (Oldfield et al., 2019).

- **Biodiversity Conservation**: Healthy soils are among the most biodiverse ecosystems on Earth, hosting microbes, fungi, and invertebrates that are crucial for ecosystem function.

- **Climate Adaptation and Resilience**: Farms with high SOC are more resilient to extreme weather events, ensuring more stable food production in a changing climate.

- **Reduced Pollution**: Improved soil structure and nutrient retention reduce runoff of fertilisers and pesticides into waterways, mitigating eutrophication.

Table 1. Estimated global soil carbon sequestration potential of agricultural practices

Practice	Sequestration Potential (kg CO_2e/ha/year)	Area of Potential Application (Million ha)	Notes
Cover Cropping	500 - 2,000	~200	Highly dependent on climate and species
No-Till/ Reduced Till	200 - 1,500	~500	Potential high in degraded soils initially
Agroforestry	1,000 - 5,000+	~100	High per-hectare rate but limited total area
Grazing Management	500 - 2,500	~3,000 (rangelands)	Improved rotational grazing systems
Organic Amendments	1,000 - 4,000	Varies	Biochar, compost application

Sources: Paustian et al., 2016 & Bossio et al., 2020

The economic value of these co-benefits is substantial. (Sanderman et al., 2017) estimated the annual cost of soil erosion, a direct result of poor soil health, to be over $8 billion in lost productivity in the United States alone.

3. CURRENT FRAMEWORKS AND THEIR LIMITATIONS

Despite its promise, soil carbon sequestration remains a peripheral component of most major climate and carbon market frameworks.

3.1 National and International Climate Policy

Under the UNFCCC, countries submit Nationally Determined Contributions (NDCs). While many NDCs now mention "agriculture" or "land use," few have specific, measurable targets for SOC enhancement. Most focus on emission reductions from livestock or fertiliser use rather than the CDR potential of soils. Integrating specific SOC targets into NDCs, as part of the Agriculture, Forestry, and Other Land Use (AFOLU) sector, is a critical next step.

3.2 Voluntary Carbon Markets (VCMS)

The VCM has been the primary driver of investment in soil carbon projects to date. Several standards exist, such as Verra’s VM0042 protocol and the Soil Enrichment Protocol under the American Carbon Registry. However, the market remains nascent and fragmented. Table 2 illustrates the growth, but also the minute scale of soil carbon credits relative to the broader market.

The price premium for soil carbon credits, as shown in Table 2, often reflects buyer interest in the agricultural co-benefits, not just the carbon itself.

3.3 Case Studies in Soil Carbon Management

The theoretical potential of soil carbon sequestration is being tested and demonstrated in various projects worldwide, which are summarised in Table 3. These case studies highlight different models of implementation, financing, and challenges, providing crucial lessons for future scaling.

3.3.1 GLOBAL case study: the Australian carbon farming initiative (CFI)

Australia's CFI, established by the government in 2011 and now part of the Emissions Reduction Fund (ERF), is one of the world's most advanced legislative frameworks for soil carbon. It provides a methodology for farmers to earn Australian Carbon Credit Units (ACCUs) for sequestering carbon through approved practices like pasture cropping, nutrient management, and grazing management.

- **Location:** Nationwide, Australia.
- **Scale:** Hundreds of projects across millions of hectares of rangeland and agricultural land.
- **Key Practices:** Adjusted stocking rates, pasture sowing, fire management, and rotational grazing.
- **Outcomes:** The program has successfully created a new income stream for farmers,

making rural properties more financially resilient. According to McDonald et al. (2023) found that participating farms showed increased ground cover and biomass production, indicating improved land health alongside carbon gains.

- **Lessons Learned:** The CFI demonstrates the critical role of government in creating a stable, regulated market. Its robust, science-based methodology has become a global benchmark. However, challenges remain, including the high upfront cost of measurement and the complexity of the application process, which can be a barrier for smaller landowners.

3.3.2 Global case study: The nori marketplace (USA)

Nori is a private, for-profit startup that represents a purely market-driven approach. It creates a direct marketplace where farmers can sell carbon removal tonnes (NRTs) to corporations and individuals seeking to offset their emissions. Nori simplifies the process by using a specific methodology focused on no-till and cover cropping, and it uses modelling and third-party verification to estimate carbon sequestration.

- **Location:** Primarily the United States.
- **Scale:** Dozens of projects, with a focus on the Corn Belt.
- **Key Practices:** Adoption of no-till and cover cropping, verified against a historical baseline.
- **Outcomes:** Nori has been successful in attracting corporate buyers interested in transparent, US-based carbon removal. It offers a streamlined process for farmers and uses a reverse auction to set prices.
- **Lessons Learned:** Nori highlights the potential for innovation in the private sector to lower transaction costs and simplify farmer participation. However, its narrow focus on a limited set of practices shows the trade-off between methodological simplicity and the comprehensive adoption of full regenerative systems. Its long-term success depends on maintaining buyer trust and ensuring the scientific rigour of its modelling approach.

3.3.3 Case study in India: the zero budget natural farming (ZBNF) programme, Andhra Pradesh

While not initially designed as a carbon project, Andhra Pradesh's ambitious ZBNF program embodies the principle of enhancing soil health for multiple benefits, including climate resilience. ZBNF promotes the elimination of chemical inputs and relies on traditional practices using locally available cow dung, cow urine, jaggery, and pulse flour to create soil amendments.

- **Location:** State of Andhra Pradesh, India.
- **Scale:** Aimed at reaching 6 million farmers and 8 million hectares of land by 2030.
- **Key Practices:** Use of *Ghanajeevamrutham* (solid inoculant) and *Jeevamrutham* (liquid inoculant) for soil fertility, cover cropping, and intercropping.
- **Outcomes:** Early reports and studies (Khader, 2019) indicate significant reductions in input costs for farmers, improved soil health (increased organic matter and water retention), and more stable yields under climate stress. The program’s primary success is in climate adaptation and farmer economic resilience.
- **Lessons Learned:** The Andhra Pradesh case is a powerful model for a state-led, agroecological transformation. Its potential for carbon sequestration is immense but remains largely unmeasured and unmonetized. It underscores a critical point: policies that promote soil health for immediate farm-level benefits (reduced costs, improved resilience) may achieve faster adoption than those focused solely on the abstract value of carbon. The challenge is to now layer robust MMRV systems onto such large-scale programs to quantify and verify their climate mitigation impact, potentially unlocking carbon finance to support further scaling.

3.3.4 Case study in India: ITC'S soil health mission

This is an example of a private-sector-led initiative driven by supply chain sustainability. Indian conglomerate ITC Limited, with significant agribusiness interests, launched a mission to

Table 2. Voluntary Carbon Market Trends (2019-2023)

Metric	2019	2021	2023 (Est.)	Notes
Total Credit Retirements ($MtCO_2e$)	104	159	~200	Market growing steadily
Nature-Based Credit Retirements	42	68	~100	~50% of the market
Soil Carbon Credit Retirements	< 0.5	~1.5	~4-5	Fast growth from a tiny base
Avg. Price per Soil Credit ($)	$4-6	$8-12	$15-25	Premium for co-benefits

Source: Synthesised from Ecosystem Marketplace reports and authors' analysis

Table 3. Summary of Soil Carbon Case Studies

Case Study	Primary Driver	Key Practices	Scale	Key Lesson
Aust. CFI	Government Policy	Grazing Management	National (Millions Ha)	Robust methodology is key; high costs are a barrier
Nori (USA)	Private Carbon Market	No-Till, Cover Crops	Dozens of Projects	Private innovation can simplify access
AP ZBNF (India)	State Gov. & Agroecology	Natural Inputs, Intercropping	Millions of Farmers	Focus on farmer economics drives adoption
ITC (India)	Corporate Supply Chain	Soil Testing, Nutrient Mgmt.	~1 million Acres	Supply chain sustainability is a powerful driver

improve soil health across its value chain. It provides soil testing, recommends tailored sustainable practices, and offers knowledge transfer to farmers from whom it sources raw materials.

- **Location:** Multiple states across India.
- **Scale:** Has reached hundreds of thousands of farmers.
- **Key Practices:** Balanced application of fertilisers, use of organic amendments, and promotion of integrated nutrient management.
- **Outcomes:** ITC reports increased SOC in project areas, higher farmer productivity, and improved quality of raw materials for its businesses. This creates a direct business case for the corporate investment.
- **Lessons Learned:** ITC's model shows how corporate supply chain investments can be a major driver of soil health improvement. It aligns the company's economic interest with environmental sustainability. This approach bypasses the complexities of the carbon market by focusing on the direct agronomic and supply chain benefits of healthy soil. However, like ZBNF, its carbon sequestration outcomes, while likely positive, are not systematically measured or monetised as verified credits

4. KEY CHALLENGES TO INTEGRATION

Scaling soil carbon programs faces significant technical, economic, and methodological hurdles.

4.1 Measurement, Monitoring, Reporting, and Verification (MMRV)

The single greatest challenge is accurate, cost-effective MMRV. Traditional SOC measurement requires repeated soil sampling and laboratory analysis, which is expensive, time-consuming, and destructive. Remote sensing and modelling offer promise but are not yet sufficiently accurate on their own for high-value carbon credits. (Batjes et al., 2024) are among many researchers developing new technologies, including in-field sensors and sophisticated ecosystem models, to lower MMRV costs.

4.2 Permanence

Permanence refers to the durability of carbon stored in soil. A credit representing one ton of sequestered CO_2 is meant to be permanent, but SOC can be re-released due to a change in management practice, a natural disaster like a wildfire, or the impacts of climate change itself (e.g., warming temperatures accelerating decomposition) (Verschuuren, 2018; Laktuka et al., 2025). Guaranteeing permanence over a 100-year timescale is inherently difficult.

Table 4. Farmer Adoption Barriers and Enablers for Soil Health Practices Barriers to Soil Carbon Sequestration

Barrier	Description	Potential Enabler
Economic Risk	High upfront cost & uncertain ROI	Carbon payments, cost-share programs, and premium markets
Knowledge Gap	Lack of know-how for new practices	Technical assistance, peer-to-peer learning networks
Cultural Norms	Deeply ingrained traditional practices	Demonstrations, champion farmers, and changing education
Land Tenure	Short-term leases disincentivise long-term investment	Longer leases, landowner-tenant agreements on soil health
Policy Disincentives	Crop insurance or subsidies favouring monocultures	Policy reform to support regenerative systems

Source: Authors' synthesis based on (Prokopy et al., 2019)

Carbon markets address this through buffer pools (where a percentage of credits is withheld to ensure against reversals) and temporary crediting mechanisms, but these solutions are imperfect.

4.3 Additionality and Baselines

A core principle of carbon markets is that credited reductions must be "additional" – they would not have occurred without the incentive of carbon finance. Establishing a counterfactual baseline for a farm's business-as-usual practices is challenging and can lead to crediting for activities that were going to happen anyway. The dynamic nature of farming systems adds to this complexity.

4.4 Leakage

Leakage occurs when a project’s activities simply displace emissions to another location. For example, a project that reduces livestock stocking density to allow for grassland recovery might cause the farmer to sell those animals to another operation that overstocks its land, resulting in no net emission reduction.

4.5 Economic and Behavioural Barriers

Transitioning to regenerative practices often involves upfront costs (e.g., for new equipment), a temporary dip in yields during the transition period, and a steep learning curve for farmers. Without sufficient financial and technical support, farmer adoption will remain low. Table 4 outlines typical barriers and enabling factors for farmers.

5. POLICY RECOMMENDATIONS

To overcome these challenges and fully integrate soil health into climate frameworks, we propose the following multi-stakeholder actions.

5.1 For Governments and Policymakers

1. **Integrate Soil Health into NDCs:** Nations should set specific, quantifiable targets for SOC increase in their AFOLU sectors and outline clear policy pathways to achieve them.
2. **Reform Agricultural Subsidies:** Shift public subsidies and incentives away from practices that degrade soils and towards those that build SOC and deliver ecosystem services. This is a powerful lever for change.
3. **Fund Public Research and Development:** Significantly increase public investment in MMRV R&D, including remote sensing, soil spectroscopy, and process-based models, to lower the cost of verification.
4. **Develop National Soil Carbon Inventories:** Establish robust, long-term monitoring networks to track changes in SOC stocks at regional and national levels, providing data to validate models and inform policy.

5.2 For Carbon Market Standards and Registries

1. **Standardise Methodologies:** Harmonise protocols for baseline setting, accounting, and MMRV across major standards to reduce complexity and increase market integrity. This includes developing tiered approaches that use advanced tech for large areas and sampling for smaller projects.
2. **Innovate on Permanence Mechanisms:** Develop and test new insurance and financial instruments to better manage reversal risks, moving beyond a one-size-fits-all buffer pool.

Table 5. Projected impact of aggressive policy support for soil health (2030)

Scenario	Estimated Sequestration (Mt CO_2e/yr)	Agricultural Area under Practice (M ha)	Estimated Annual Investment Needed
Business-as-Usual	~500	~100	~$5 Billion
Ambitious Policy Action	~1,500 - 2,000	~400	~$25 - $40 Billion
Key Drivers of Difference		Advanced MMRV, full subsidy reform, high carbon price	Blended public-private finance

Source: Authors' projection based on (Bossio et al., 2020; Fuss et al., 2018)

3. **Value Co-Benefits:** Create mechanisms to monetise or formally recognise the water, biodiversity, and social co-benefits of soil health projects, allowing farmers to capture more value. This could involve bundling credits or creating new ecosystem service certificates.

5.3 For Corporate and Financial Actors

1. **Adopt Beyond-Value-Chain Mitigation (BVCM):** Corporations should invest in high-quality soil carbon projects as part of their comprehensive climate strategies, following guidelines from initiatives like the Science Based Targets initiative (SBTi) for BVCM.
2. **Offer Transition Finance**: Banks and impact investors should develop loan products with favourable terms for farmers transitioning to regenerative practices, using future carbon credit revenue as collateral.
3. **Engage in Pre-Competitive Collaboration**: Companies within agricultural supply chains should collaborate on pre-competitive initiatives to develop shared standards and pool resources for funding the transition to regenerative agriculture among their suppliers.

The potential impact of a concerted policy effort is significant, as modelled in Table 5.

6. CONCLUSION

Soil health is not a silver bullet for the climate crisis, but it is a foundational element of any successful strategy to achieve a net-zero future. The integration of soil carbon sequestration into climate and carbon market frameworks offers a rare triple dividend: mitigating climate change, enhancing global food and water security, and restoring biodiversity. The path forward requires breaking down silos. Climate policymakers must engage deeply with agricultural experts. Carbon market architects must work with soil scientists to build rigorous, cost-effective, and fair systems. Most importantly, farmers must be centred as partners and protagonists in this transition, fairly compensated for their role as stewards of a global common. The barriers MMRV, permanence, and additionality are significant but not insurmountable. There are technical and methodological problems that can be solved through targeted research, policy innovation, and collaborative will. By adopting the recommendations outlined in this paper, stakeholders can unlock the immense potential of the earth beneath our feet to help stabilise the atmosphere above it. The time to invest in soil health is now.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of this manuscript.

Details of the AI usage are given below:

1. Gemini and Grammarly were used for language editing.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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