

CHAPTER 5

TOWARD A JURISDICTIONAL SOIL CARBON STRATEGY IN THE STATE TERRITORY: EXPANDING THE BASKET OF SUSTAINABLE PRODUCTS IN RURAL PROPERTIES IN RIO DE JANEIRO

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1. INTRODUCTION

Soil carbon credits emerge not as a silver bullet for addressing the need to mitigate emissions resulting from climate change, but rather as one more product within the basket of options available to rural producers committed to conservation or regenerative agriculture. These practices foster agricultural systems that interconnect environmental, animal, and human health — the principle of “One Health.”

Although methodological divergences and different protocols still exist regarding the general principles of carbon credit accounting, it is necessary to collect data, build information systems, and establish measurable pathways to assess the contribution of soil management to carbon sequestration and climate mitigation.

Without integrity of information and robust data collection, the market cannot consolidate or gain credibility to provide effective responses to emission mitigation. In this sense, this contribution from the state of Rio de Janeiro, in partnership with Embrapa Soils, aims to clarify possible approaches for estimating the initial stock of soil organic carbon, as well as for modeling and measuring changes in this stock over time, always grounded in science.

The content presented here is a foundation for building public policies that focus on the potential of rural areas — beyond food and commodity production — to materialize emerging ecosystem services derived from soil and associated with sustainable agricultural practices.

The era of climate consequences reinforces the need for solutions that generate multiple outcomes and engage various economic

sectors. Reducing fossil fuel consumption is crucial; transforming energy generation chains toward using renewable sources is essential; expanding and conserving forest areas is central; and producing food while conserving soil and biodiversity is an integral part of this solution set.

Part of the solution literally lies beneath our feet. Over the past century, the conversion of natural ecosystems into agricultural ones, combined with harmful practices — such as deep and repetitive plowing, extensive monocultures, excessive chemical fertilization, overgrazing, and the absence of mechanical and vegetative soil conservation measures — has caused a reduction of 25% to 75% in the global stock of soil organic matter (Lal, 2011; Sanderman; Hengl; Fiske, 2017).

Public policies that promote sustainable agricultural practices can reverse this trend. Among these practices are the use of cover crops and green manures, reduced soil disturbance, control of overgrazing, efficient nutrient management, and diversification of production systems (Balieiro *et al.*, 2024). These methods have shown potential for restoring soil organic matter stocks (Dupla *et al.*, 2024).

2. QUANTIFICATION OF SOIL ORGANIC CARBON

One of the incentives for adopting these practices is the agricultural soil carbon credit (SCC). SCCs are tradable certificates that allow farmers who implement carbon sequestration practices to sell their emission reductions to organizations interested in offsetting their CO₂ footprint — a mechanism still little disseminated or discussed in Brazil.

These transactions currently take place in voluntary carbon markets, regulated by public or private entities. In 2022, the total global volume of SCC transactions reached 5.1 MtCO₂e (CO₂ equivalent), generating about US\$ 50.1 million in value (Mikolajczyk; Bravo, 2023). Experts project that this market could reach between US\$ 10 and 40 billion by 2030 (The Voluntary Carbon Market Is Thriving, 2022).

Following the enactment of Federal Law n° 15.042 of December 11, 2024, which establishes the Brazilian Greenhouse Gas Emissions Trading System (SBCE, in portuguese), it becomes necessary to develop measurement, reporting, and verification (MRV) protocols that consider the country's ecological characteristics and agricultural management practices. Additionally, maintaining a matrix of permanence and additionality indicators is required for the future generation and comparison of carbon credits.

The lack of standardization, combined with the diversity of agricultural practices, makes it difficult to ensure reliable monitoring and assessment of real and net climate benefits. A national or subnational MRV system — established through clear regulations accessible to the public, incorporating quality control guarantees, and based on institutional and international agreements — would facilitate accountability consistent with the national context (FAO, 2013).

The approach presented in this publication for quantifying soil organic carbon is grounded in current soil science practices. It ranges from soil sampling within a regional grid — following standards of the National Forest Inventory of the state of Rio de Janeiro (IFN/RJ) — to the integration of process-based modeling and remote sensing. This demonstrates that

it is possible, on a national scale, to develop and implement robust methods for generating data and information on soil carbon stocks.

Agricultural practices aimed at increasing soil organic carbon can deliver several co-benefits, such as improved water quality, higher productivity, and greater crop resilience (Chaer *et al.*, 2023; Balieiro *et al.*, 2024; Cavaliere-Polizeli *et al.*, 2024). Therefore, even though uncertainties remain regarding their potential for climate mitigation, efforts to build soil carbon remain highly valuable.

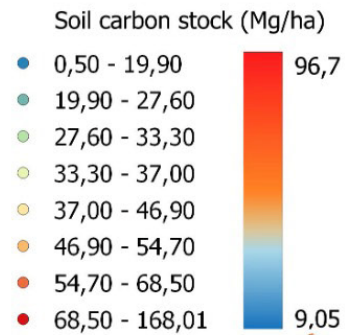
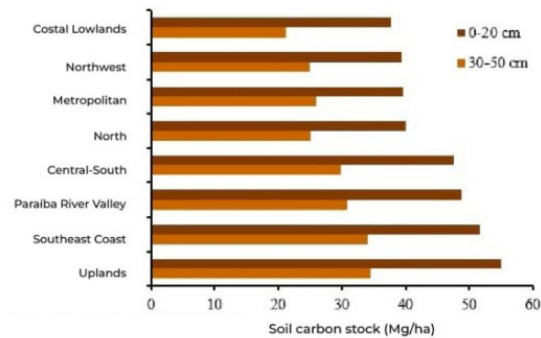
In an innovative way, the conceptual model presented in this study allows for the use of jurisdictional monitoring units and facilitates regional carbon accounting, minimizing monitoring costs for farmers and promoting large-scale implementation of agricultural practices that reduce emissions and store carbon (Figure 1).



FIGURE 1. Soil Carbon Stock across the Territory of the State of Rio de Janeiro

Source: Authors (more information available in Chapter 2).

Soil carbon stock in the state of Rio de Janeiro



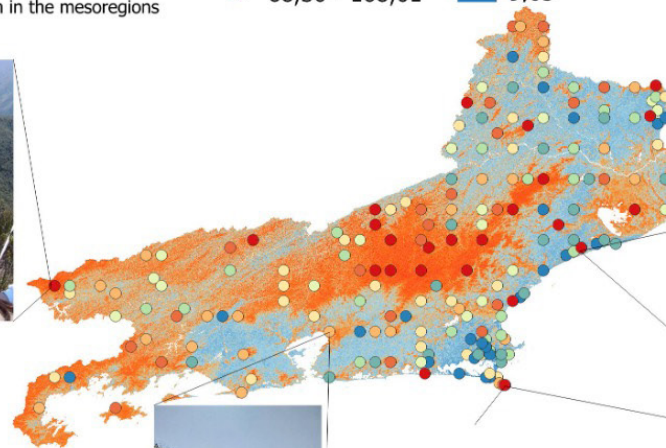
Soil carbon stocks in Rio de Janeiro state add up to ~189 million tons (189 Tg; 1 Tg = 10¹² g) at 0-20 cm, and ~119 million tons (119 Tg) at 30-50 cm, respectively.

The largest soil carbon stocks in Rio de Janeiro State are at the mountainous, high-altitude portion of the state at the Serra do Mar (in the Serrana and Costa Verde regions) and Serra da Mantiqueira (in the Médio Paraíba region) mountain ranges, and at the mangroves close to the coast, mainly at the Paraíba do Sul River delta at the eastern state boundary in the Norte Fluminense region.

Mean soil carbon stocks at 0-20 and 30-50 cm in the mesoregions of Rio de Janeiro state.



Montane grassland.



Coastal sandy vegetation



QR Code for depth of 0 - 20 cm



QR Code for depth of 30 - 50 cm



Mangrove vegetation



Submontane Dense Ombrophilous Forest.

3. JURISDICTIONAL PROJECT FOR INCREASING SOIL CARBON

This regional model for soil carbon assessment, linked to policies that promote sustainable agri-food systems, broadens the opportunities for increasing the income of rural producers. Through the State Policy for Sustainable Rural Development, Agroecology, and Organic Production in the State of Rio de Janeiro (State Law nº 8.625/2019), aligned with the National Policy on Payments for Environmental Services (Federal Law nº 14.119/2021), and applied jointly with the Agroecological Transition Assessment Tool (IATA)¹ for agroecosystems and the consolidation of the SBCE, Brazil strengthens its position not only as a major food producer but also as a key player in generating carbon credits derived from forests and soils, thus creating a new environmental commodity.

However, MRV tools, as well as contract and payment models, must take into account the productive and social dynamics of small and medium-sized farmers. Without consistent public policies, direct economic incentives accessible to farmers, technical assistance, rural extension, and continuous monitoring, little progress will be made toward an effective carbon credit market.

The central goal for a future Jurisdictional Project for Increasing Soil Carbon should be to establish technical and financial guidelines and instruments that enable the recognition of soil carbon as both an environmental and economic asset. This includes generating credits for the carbon market but especially supporting Payments for

Environmental Services (PES), thereby contributing to carbon removal from the atmosphere, environmental regeneration, and sustainable development of rural properties in Rio de Janeiro.

Technical studies have shown that practices such as reforestation and agroforestry systems (AFS) are effective in increasing soil organic carbon (SOC). Results indicate gains of up to 49% in SOC stock in reforested areas (Macedo *et al.*, 2008) and up to 24% in AFS, when compared to conventional pasture areas (Matos *et al.*, 2022). These data demonstrate both the environmental feasibility and economic potential of these strategies.

The state of Rio de Janeiro, with established initiatives such as the Projeto Conexão Mata Atlântica², is well positioned to expand its role in the emerging carbon credit market, generating environmental, social, and economic benefits. The development of technological infrastructure for soil carbon monitoring is one of the strategic recommendations of this Jurisdictional Project.

It can be concluded that the creation of a soil carbon market is desirable and viable, provided there is coordination among public policies, financial resources, technical training, and certification systems based on national metrics with international recognition.

¹ State regulation: Resolução Conjunta SEAPPA/SEAS/EMATER-RIO/INEA nº 16/2024 and Nota Técnica SEAS/SEAPPA/EMATER-RIO nº 01/2024.

² Conexão Mata Atlântica Project, learn more at: <https://mataatlantica.inea.rj.gov.br/inicio> and <https://conexaomataatlantica.mctic.gov.br/cma/portal/>.

Nature-based Solutions (NbS) encompass a variety of approaches that use ecosystems as the foundation for addressing socio-environmental challenges. These solutions hold great potential to restore, preserve, and enhance ecosystems, while significantly contributing to climate change mitigation (Maia *et al.*, 2022). Among NbS-related mitigation actions, soil plays a crucial role as the largest carbon reservoir in the Earth's surface (see Chapter 2 – *Soil Carbon Stock Maps for the State of Rio de Janeiro: inputs for carbon market opportunities*) (Paustian *et al.*, 2016), making it a key element in building resilient landscapes within the state.

The development of a Jurisdictional Project focused on generating soil carbon credits in the state of Rio de Janeiro seeks to define principles and guidelines that establish its potential as an economic asset connected to the carbon market. This proposal integrates agricultural management with other activities such as crop-livestock-forest systems and ecological restoration. The process aims to make carbon credit commercialization viable while strengthening the state's agricultural sector through the empowerment of farmers and rural landowners across Rio de Janeiro.

4. SOIL CARBON AS AN ENVIRONMENTAL ASSET

The commercialization of carbon credits and Payments for Environmental Services (PES) are financial mechanisms designed to recognize the economic value of environmental conservation, but they differ fundamentally in their structure and objectives (Munhoz; Vargas, 2022).

The commercialization of carbon credits refers to the generation and sale of certificates that represent the reduction or removal of greenhouse gases (GHGs) from the atmosphere — a market-oriented

approach to emission offsetting (Souza, 2022). These credits can be voluntarily acquired by companies and individuals seeking to offset their emissions, or they can be used in regulated markets to meet targets established under climate policies (Brazil, 2024). The certification process for carbon credits follows international standards and requires validation by independent auditors to ensure the environmental integrity of the GHG reductions or removals (Souza, 2022).

PES, on the other hand, is a financial mechanism aimed at compensating rural producers, family farmers, settlers, as well as traditional communities and indigenous peoples, for the environmental services they provide, which generate benefits for society as a whole (WRI Brasil, 2021). These services may include conserving native vegetation, restoring degraded areas and forests, improving water quality, removing carbon, or conserving biodiversity, which, for instance, benefits agricultural production through pollination (Prado *et al.*, 2016; WRI Brasil, 2021).

Soil carbon sequestration represents a valuable ecosystem service that can be compensated through PES programs, regardless of its commercialization in the carbon credit market. Therefore, it is essential to adopt an approach that incorporates both pathways — the generation of carbon credits and the recognition of soil carbon as an economic asset under PES — ensuring multiple incentives for soil conservation and sustainable management, particularly benefiting rural producers (Prado *et al.*, 2022).

Unlike carbon credit trading, which focuses on emission offsetting in relatively “closed” markets and on climate change mitigation, PES can encompass various positive environmental externalities, with payments that may take the form of money, goods, or services (Prado *et al.*, 2016,

2022; Souza, 2022). Moreover, PES may be financed by either the private sector or public policies, aiming to encourage sustainable practices and secure long-term environmental benefits.

In other words, carbon credit trading takes place within a structured market in which certified credits are sold to offset emissions, either through regulated or voluntary mechanisms. PES, when considering soil carbon as an environmental asset, does not necessarily depend on a formal market. It is often implemented through public policy or private incentives for environmental conservation. While the carbon market focuses on emission compensation, PES seeks to foster sustainable practices through direct payments, generating externalities that are tangible and socially recognized (Munhoz; Vargas, 2022; Souza, 2022).

Regenerative or conservation agriculture, when linked to a jurisdictional carbon strategy, requires coordinated action with farmers as the central actors. Large-scale restoration across the state of Rio de Janeiro will only be possible through the participation of farmers and rural landowners, who are the main land managers and stewards of ecosystems, bearing the inherent risks of such activities. This means that mechanisms must be developed to finance regeneration and restoration of the Atlantic Forest at multiple scales within the state, promoting sound soil management practices while aligning with broader state ecological goals related to biodiversity conservation and water security.

Ensuring that farmers in Rio de Janeiro are recognized as providers of goods and services for both rural and urban society is a key objective of the State Secretariat for Environment and Sustainability (SEAS) and other state institutions. The first steps have been taken through shared agendas and collaboratively developed solutions — as demonstrated in this publication.

The Agroecological Transition Assessment Tool (IATA), currently under implementation, will allow the state to monitor production systems across different macro-regions and assess the evolution of their soils. A carbon analysis laboratory — using green chemistry-based methods — and a database for storing this information will support the interpretation of carbon accumulation or loss trends in Rio de Janeiro's agroecosystems, providing the foundation for PES policies targeting farmers.

Initial steps have been taken toward building a public policy framework that aims to conserve the Atlantic Forest and strengthen regenerative agriculture, thereby improving the quality of life in rural, forested, and urban areas throughout the state.

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