

Preliminary datasets from a meta-analysis on soil organic carbon under regenerative agricultural systems in Brazilian family farming

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Note: Preliminary text written by Generative Artificial Intelligence with human results interpretation and text elaboration support.

Abstract

This preliminary meta-analysis compiles field-scale experimental evidence on soil organic carbon (SOC) responses to regenerative agricultural systems in Brazilian family farming, including no-tillage vegetable systems (SPDH), agroforestry systems (SAF) and organic/agroecological management. The analysis integrates more than 20 independent comparisons across multiple regions, soil types and production contexts, comparing regenerative systems against conventional management. Across all three system types, regenerative practices consistently increased SOC relative to conventional systems, although with substantial heterogeneity, reflecting strong environmental and management-dependent controls, beyond environmental characteristics associated to different Brazilian biomes.

1. SPDH Systems (No-tillage vegetable systems): The first dataset includes studies totaling 56 observations comparing SPDH systems to conventional tillage. The random effects model yielded a significant positive mean difference (MD) in SOC content of 5.27 [3.06; 7.48], indicating that SPDH consistently outperformed conventional systems in increasing surface SOC. This outcome aligns with the expected benefits of reduced soil disturbance, increased residue retention, and microbial activity. However, heterogeneity was high ($I^2 = 100\%$), underscoring the influence of contextual factors such as soil texture, duration of adoption, and crop type. Some studies, like Kuneski et al. (2023a), reported particularly large SOC gains, suggesting high responsiveness under certain management configurations. No-tillage vegetable systems (SPDH). SPDH also shows a clear positive SOC effect. The random-effects estimate is 5.27 SOC units (95% CI: 3.06 to

7.48). This indicates that residue retention, reduced soil disturbance and diversified rotations in horticultural family farming led to significant carbon accumulation even over relatively short time frames. Despite extremely high heterogeneity ($I^2 = 100\%$), all aggregated effects remain strongly positive, confirming SPDH as a reliable soil carbon enhancement pathway in intensive vegetable systems. Beyond SOC gains, SPDH systems also offer broader agroecosystem benefits, including reduced need for chemical inputs, improved water production, enhanced microbial communities and biodiversity, thermal regulation, and reduced losses of soil, water, and nutrients through water erosion.

2. SAF Systems (Agroforestry systems): The second forest plot compiles independent comparisons of agroforestry systems, incorporating both alleys cropping and multistrata arrangements. The random effects model showed a moderate but statistically significant SOC increase of 3.38 [0.62; 6.14] relative to conventional systems. Despite lower effect sizes compared to SPDH and ORG systems, agroforestry systems exhibited high variability in outcomes ($I^2 = 95.9\%$). The wide confidence intervals for some studies (e.g., de Souza et al. 2023; Rossi et al. 2023) reflect the complex interplay of factors such as tree species diversity, planting density, root distribution, and litter inputs. These findings support the premise that agroforestry systems enhance SOC, especially over longer timeframes, but results can vary depending on design and local conditions. In addition to SOC improvements, agroforestry systems also contribute to reduced reliance on synthetic inputs, enhanced water cycling, support for beneficial soil microbiota and biodiversity, microclimate regulation, and mitigation of soil, water, and nutrient losses by water erosion.

3. Organic and Agroecological Systems (ORG/AGRO): The third dataset examines SOC responses under organic and agroecological management across 34 observations. The random effects model revealed the highest overall mean SOC increase among the systems studied, with an MD of 10.52 [2.71; 18.33]. Although the number of studies was smaller, the effect size was more pronounced, potentially due to synergistic effects of organic inputs, diversified crop rotations, and the absence of synthetic chemical inputs. Again, heterogeneity was very high ($I^2 = 100\%$), suggesting that outcomes are highly dependent on site-specific practices. The results from Lima et al. (2015), showing a MD above 34, illustrate the potential for strong SOC gains when organic practices are well-established and adapted to local conditions. Despite the high accumulation of SOC observed, future studies are needed to evaluate the lability of soil organic matter, as the input of external organic sources may mask the long-term sustainability of this increase.

Conclusion: The results of this preliminary meta-analysis provide consistent evidence that regenerative agricultural practices adopted by Brazilian family

farmers — including no-tillage vegetable systems (SPDH), agroforestry systems (SAF), and organic/agroecological management — significantly increase soil organic carbon (SOC) compared to conventional practices. These findings reinforce the potential of regenerative agriculture as a nature-based solution aligned with multiple Sustainable Development Goals (SDGs), especially SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land). Despite their demonstrated environmental benefits, these systems still lack broad institutional support under current Brazilian agricultural policies, which often fail to adequately reach family farming sectors with incentives, credit, or technical assistance focused on regenerative approaches. In this context, the outcomes of this study also echo into key recommendations from the Intergovernmental Panel on Climate Change (IPCC) regarding the need for climate justice and a just transition — emphasizing that low-emission, resilient farming pathways ensure equitable access to resources, recognize traditional knowledge, and prioritize the empowerment of smallholders and marginalized communities. Scaling up regenerative practices in family farming can therefore serve as a strategic lever to bridge the gap between climate mitigation goals and social equity, supporting a more inclusive and sustainable transformation of rural territories in Brazil.