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Influence of Organic and Conventional Farming on Soil Carbon Sequestration and Organic Matter Content

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Abstract: *This paper critically examines the influence of organic versus conventional farming practices on soil organic carbon (SOC) sequestration and soil organic matter (SOM) content. While organic farming is widely promoted as a climate-smart agricultural practice capable of enhancing soil carbon stocks, the empirical evidence presents a more nuanced picture. Meta-analyses and long-term trials demonstrate that organic systems generally increase SOC concentrations and mass storage compared to conventional systems, with estimates suggesting 44% more humus content under organic management . However, critical analysis reveals that these benefits are predominantly driven by specific management practices—particularly the application of organic amendments and crop rotation design—rather than organic certification per se . When organic and conventional farms with comparable organic fertilizer application rates are compared, differences in SOC often diminish or disappear . Soil texture, pH, and intrinsic soil properties significantly mediate the magnitude of carbon sequestration benefits, with fine-textured soils showing the greatest response to organic management . Furthermore, crop residue traits, particularly leaf and root nitrogen content, play a crucial role in determining SOC sequestration responses . This paper synthesizes findings from global meta-analyses, chronosequence studies, and on-farm datasets to provide a comprehensive assessment of the factors governing soil carbon dynamics in contrasting farming systems, offering evidence-based recommendations for sustainable soil management.*

Keywords: Soil Organic Carbon, Organic Farming, Conventional Farming, Carbon Sequestration, Soil Organic Matter, Sustainable Agriculture

I. INTRODUCTION

Soil organic carbon (SOC) is a critical determinant of soil health, agricultural productivity, and ecosystem resilience. It influences soil structure, water-holding capacity, nutrient availability, and microbial activity, while also serving as a significant terrestrial carbon sink that can mitigate anthropogenic CO_2 emissions . Agricultural management practices exert strong control over SOC dynamics by affecting both the inputs (crop residues, organic amendments) and turnover rates of soil organic matter (SOM) .

The comparative performance of organic and conventional farming systems in building soil carbon has become a central question in sustainable agriculture discourse. Organic farming, which prohibits synthetic fertilizers and pesticides while emphasizing diverse crop rotations, organic fertilization, and biological pest control, is widely believed to enhance SOM content and sequester carbon . Estimates suggest that organic farming can sequester approximately 3.5 tonnes of CO_2 per hectare annually, far exceeding conventional methods .

However, the scientific basis for these claims requires careful scrutiny. The designation "organic farming" encompasses a bundle of practices rather than a single, uniform intervention . Crop rotation, organic fertilization, reduced external inputs, and abandonment of synthetic chemicals all contribute to SOC dynamics, but none of these practices is uniquely organic . Consequently, observed differences in SOC between organic and conventional systems may reflect disparities in specific management factors—particularly organic amendment application rates—rather than inherent advantages of organic certification.

This paper aims to critically evaluate the influence of organic versus conventional farming on soil carbon sequestration and organic matter content by synthesizing evidence from global meta-analyses, long-term field experiments, chronosequence studies, and on-farm comparative assessments. The analysis considers the roles of soil texture, climate, management intensity, crop traits, and confounding factors that complicate interpretation of comparative studies.

II. METHODOLOGICAL CONSIDERATIONS IN COMPARING FARMING SYSTEMS

2.1 Challenges in Experimental Design

Comparing organic and conventional farming systems presents significant methodological challenges. A critical review of 68 datasets from 32 peer-reviewed publications revealed that 34 out of 68 datasets lacked a true control with well-defined starting conditions, making it impossible to establish causality . Many studies reported SOC concentrations rather than mass stocks, neglecting potential changes in soil bulk density that could mask or exaggerate treatment effects .

A further complication is that in 37 out of 50 cases, the amount of organic fertilizer applied in the organic system exceeded that applied in the compared conventional system, and in half of the cases, crop rotations differed between systems . This confounding of system-level differences with specific management practices has led to overattribution of SOC benefits to organic farming per se rather than to higher organic inputs.

2.2 The Importance of Baseline and Mass Measurements

The distinction between SOC concentration (percentage) and SOC mass storage (quantity per unit area) is critical. Studies reporting only concentrations may show apparent increases in SOC that are actually due to reduced soil bulk density rather than genuine carbon accumulation. Conversely, mass storage measurements account for changes in soil volume and provide more accurate estimates of carbon sequestration .

Additionally, the absence of baseline measurements—the initial SOC content before conversion to organic management—limits the ability to distinguish management-induced changes from pre-existing differences. Long-term comparisons with documented starting conditions provide more robust evidence than single-point "paired" comparisons .

III. EVIDENCE FOR ENHANCED SOIL CARBON UNDER ORGANIC MANAGEMENT

3.1 Meta-Analyses and Global Syntheses

A comprehensive 2024 meta-analysis covering data from 1950 to 2023 found a significant increase in SOC under organic agriculture . Analysis of response ratios for SOC concentration showed a 95% confidence interval of 0.089–0.149, while carbon storage data indicated a 95% confidence interval of 0.053–0.205. These increases, while variable, confirm the statistically positive impact of organic farming on SOC .

A global meta-analysis published in 2010 showed that after conversion to organic farming, SOC in organic systems increased annually by 2.2% on average, whereas SOC in conventional systems did not change significantly . Similarly, long-term trials and meta-analyses confirm higher soil organic matter content and improved soil structure in organic systems compared to conventional counterparts .

3.2 Soil Texture as a Mediating Factor

Soil texture plays a significant role in mediating the effects of organic farming on SOC dynamics. The 2024 meta-analysis found that fine soil textures demonstrated the highest mean response ratios for both SOC concentration (0.163) and mass storage (0.173), suggesting that clay-dominated soils are particularly responsive to organic management .

A long-term chronosequence study on clay-dominated soils (0–34 years of organic farming) revealed that organic farming can increase total SOC content and labile organic carbon fractions over time, particularly in soils with low iron oxide content . However, in sand-dominated soils (0–69 years of organic farming), the duration of organic farming did not affect SOC content or quality, potentially because management practices influencing SOC cycling were not sufficiently distinctive between organic and conventional systems in the sand chronosequence . This finding underscores the importance of intrinsic soil properties for SOC dynamics and the need for soil-specific management recommendations.

3.3 Organic Carbon Quality and Stability

Beyond total carbon quantity, the quality and stability of SOC are important considerations. The chronosequence study using four complementary techniques (permanganate oxidizable carbon, Rock-Eval thermal analysis, size fractionation into particulate and mineral-associated organic matter, and elemental C:N analysis) found that organic farming can increase labile organic carbon fractions, resulting in lower overall SOC stability . This suggests that while organic management increases total SOC, the additional carbon may be more bioavailable and potentially more vulnerable to mineralization.

Conversely, research from semi-arid tropics found that organic manures increased microbial biomass carbon by 117% and dissolved organic carbon concentration by 181% over conventional farming, with evidence that organic matter is better protected in organic soils and consequently less vulnerable to mineralization .

3.4 Microbial Community and Biological Activity

Organic farming enhances microbial health, reflecting a more active microbial community important for nutrient cycling. A study of rice-based cropping systems found microbial biomass carbon at 194.0 $\mu g\ g^{-1}$, microbial biomass nitrogen at 134.2 $\mu g\ g^{-1}$, and dehydrogenase activity at 36.80 μg TPF $h^{-1}\ g^{-1}$ under organic management . These indicators suggest enhanced biological activity that supports soil carbon dynamics.

IV. CRITICAL PERSPECTIVES AND CONFOUNDING FACTORS

4.1 The Role of Organic Amendments

The most significant confound in comparing organic and conventional farming is the application of organic amendments. A critical analysis of field experiments found that the beneficial effects of organic farming on SOC are largely determined by higher and often disproportionate application of organic fertilizer compared to conventional farming . In the few studies where crop rotation and organic fertilization were comparable in both systems, no consistent difference in SOC was found .

This finding is reinforced by an analysis of actual farms in Germany, which found that organic and conventional farms had similar levels of organic amendments—contrary to the common assumption that organic farms use more manure or compost . When application rates of organic fertilizers were comparable, SOC levels were similar between systems. The proportion of farms without livestock was also comparable: 29% in organic farming and 32% in conventional farming .

The implication is that it is the practice of applying organic amendments, not organic farming certification per se, that gives the soil-building benefit. Conventional farms can and do use organic amendments, and when they do, they can build soil just as well as organic farms .

4.2 Nitrogen Availability and Crop Yields

Nitrogen availability is a dominant factor influencing crop productivity and, consequently, plant biomass inputs to soil. Organic farms often have lower available nitrogen, leading to lower crop yields and lower biomass inputs, which can offset the benefits of favorable crop rotations and cover cropping .

Research on German farms found that while organic farms had significantly higher proportions of SOC-enhancing crops (e.g., clover grass and forage legumes) in their rotations and used slightly more cover crops (14% vs 11% of crop-years), these advantages were negated by lower crop yields due to nutrient limitations .

4.3 Crop Traits and Litter Quality

Recent research highlights that crop residue traits play a significant role in SOC sequestration responses. A global meta-analysis coupled with field measurements across a European network found that crop species displaying resource-acquisitive traits—particularly high leaf and root nitrogen—increase the difference in SOC between organic and conventional farming . Changes towards higher crop residue decomposability were associated with decreased SOC stocks under conventional farming .

This finding provides a clear message for land managers: the choice of crop species, and more importantly their functional traits, should be considered alongside management practices and climate when evaluating the potential of organic farming for climate change mitigation .

4.4 Life Cycle Assessment and Net Carbon Flux

A life cycle perspective reveals trade-offs in carbon dynamics. A study of olive systems found that organic systems had higher global greenhouse gas emissions due to manure fertilization rather than the synthetic foliar fertilizers used in conventional systems . However, manure was also the primary reason for higher SOC content and soil carbon sequestration in the organic system, with fertilization activity accounting for approximately 80% of total emissions in the organic system versus 45% in the conventional system .

The contribution of manure to increased SOC compensated for the higher carbon emissions, resulting in higher negative net carbon flux in the organic versus conventional system (-1.7 vs -0.52 t C ha^{-1} $year^{-1}$) and higher efficiency of CO_2 mitigation in the organic system .

V. SYNTHESIS AND IMPLICATIONS

5.1 The Primacy of Practices over Labels

The weight of evidence suggests that soil carbon outcomes depend more on specific management practices—organic amendment application, crop rotation design, plant biomass inputs, and tillage intensity—than on organic versus conventional certification status . The main positive driver of soil health is plant biomass input from whatever source, and the main negative driver is tillage. These strong causal drivers can mask weaker contributing factors .

When organic and conventional farms with similar rates of organic amendments are compared, the results are similar . This indicates that the use or non-use of synthetic pesticides is not the determining factor for SOC; rather, whichever system has the most positive balance of plant biomass inputs minus tillage losses will have the most soil organic matter.

5.2 Context-Dependent Benefits

The benefits of organic farming for soil carbon are context-dependent. Fine-textured soils with low iron oxide content show the greatest response to organic management . Organic farming can increase total SOC content and labile carbon fractions over time, particularly in clay-dominated soils where management practices are distinctive . However, in sand-dominated soils, intrinsic properties may limit the capacity for carbon accumulation, and management differences may be less impactful .

Furthermore, the limited supply of organic amendments means that the rates needed to substantially increase soil organic matter are not scalable to all croplands . Those with access to manure or compost benefit, but those without must manage with lower soil health outcomes.

5.3 Implications for Policy and Practice

These findings have significant implications for agricultural policy and practice:

Promote practice-based interventions: Rather than focusing solely on organic certification, policies should incentivize specific practices known to build soil carbon—organic amendments, diverse rotations, cover cropping, and reduced tillage—that can be adopted in both organic and conventional systems .

Consider soil-specific recommendations: Given the importance of intrinsic soil properties for SOC dynamics, soil-specific farm management recommendations are needed . Management interventions should be tailored to soil texture, mineralogy, and existing carbon levels.

Integrate crop trait considerations: The choice of crop species with resource-acquisitive traits (high leaf and root nitrogen) can enhance SOC sequestration in organic systems . Breeding and selection programs should consider these functional traits.

Address nitrogen limitations: Yield gaps in organic systems due to nitrogen limitations can reduce biomass inputs and offset rotation benefits . Strategies to enhance nitrogen availability while maintaining organic principles are needed.

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VI. CONCLUSION

The influence of organic versus conventional farming on soil carbon sequestration and organic matter content is complex and context-dependent. While meta-analyses demonstrate that organic systems generally enhance SOC concentrations and mass storage compared to conventional systems, these benefits are largely driven by specific management practices—particularly organic amendment application and crop rotation design—rather than organic certification per se. When these practices are comparable between systems, differences in SOC often disappear.

Soil texture, pH, and intrinsic soil properties significantly mediate the magnitude of carbon sequestration benefits, with fine-textured soils showing the greatest response to organic management. Crop residue traits, particularly leaf and root nitrogen content, also play a crucial role in determining SOC sequestration responses. The evidence suggests that a practice-based approach to soil carbon management—one that promotes organic amendments, diverse rotations, and reduced tillage across all farming systems—may be more effective than a focus on organic certification alone. This perspective enables more nuanced and effective policy interventions for climate change mitigation and soil health improvement.

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