Plant- and microbial-derived carbon contributions to particulate and mineral-associated organic carbon in perennial and annual cropping systems

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Highlights

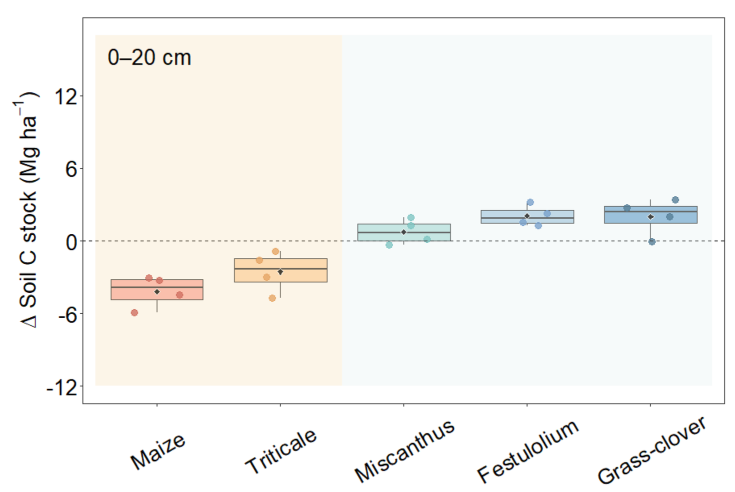
- **Soil POC, MAOC, and their components were quantified for perennial and annual cropping systems based on an 11-year field experiment.**
- **Perennials had significantly higher POC and MAOC in the 0–20 cm topsoil.**
- **Microbial necromass C accounted for 29% of POC and 36% of MAOC in the topsoil.**
- **In cold climates, plant-derived C may dominate POC and MAOC.**

Introduction

Enhancing soil organic carbon (SOC) storage, particularly its stable fractions, is critical for mitigating global climate change. **Perennial crops** are believed to have great potential to increase SOC, however, their effects on labile and stable C fractions remain uncertain. Particulate organic carbon (**POC**) and mineral-associated organic carbon (**MAOC**) are considered to have different stabilities and different formation mechanisms. **Plant-** and **microbial-derived C** are the main sources of SOC, yet their contributions to the two C fractions are not fully understood.

In our previous study based on a 9-year field experiment, three perennial cropping systems significantly increased topsoil C stock compared to the two annual cropping systems (Shang et al., 2024).

Here, we compared these two perennial cropping systems with maize monoculture to investigate their effects on soil POC and MAOC, and to quantify the contributions of plant- and microbial-derived C to these two soil C fractions.

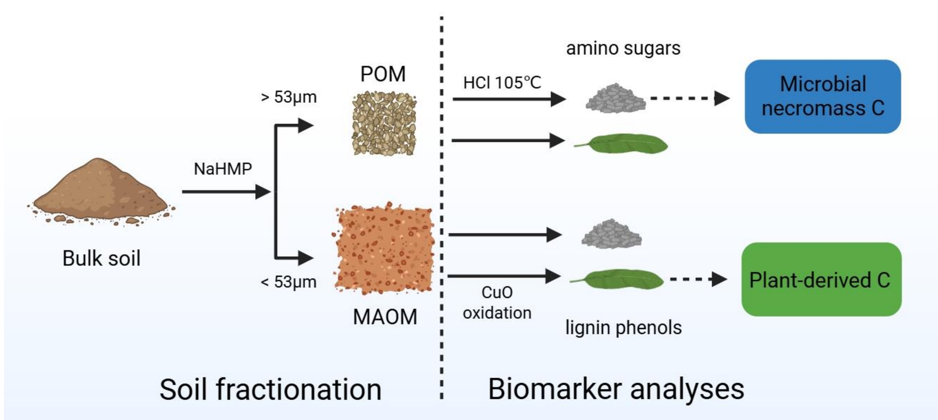


We hypothesize that (i) festulolium and grass-clover have higher POC and MAOC compared to maize; and (ii) POC under the two perennial cropping systems is predominantly derived from plant-derived C, while their MAOC is primarily composed of microbial necromass C.

Materials and Methods

The experiment was established in 2012 on a sandy loam soil, located in AU Viborg, Denmark (56°30′N, 9°35′E). The climate is cold and humid temperate. An incomplete split-plot design with four replicate blocks was implemented. Maize was sown in May and harvested as a whole crop in October, receiving 140–200 kg N ha^{-1} per year. Festulolium and grass-clover mixture (including red clover, festulolium, and cock's-foot) were sown in May 2012 and harvested 3–4 times per year. Festulolium received 425–500 kg N ha^{-1} per year, while grass-clover mainly relied on the biological N fixation of clover.

Bulk soil samples was fractionated into POM and MAOM fractions using wet sieving method, and the contributions of plant- and microbial-derived C were quantified using biomarkers.



Results

1. Higher POC and MAOC under perennial cropping systems.

In the 0-20 cm soil , festulolium (2.0 g kg^{-1}) and grass-clover (2.2 g kg^{-1}) showed significantly higher POC content than maize (1.4 g kg^{-1}) (Fig. 1). Festulolium (12.3 g kg^{-1}) and grass-clover (11.7 g kg^{-1}) also had higher MAOC content than maize (10.9 g kg^{-1}) at 0–20 cm.

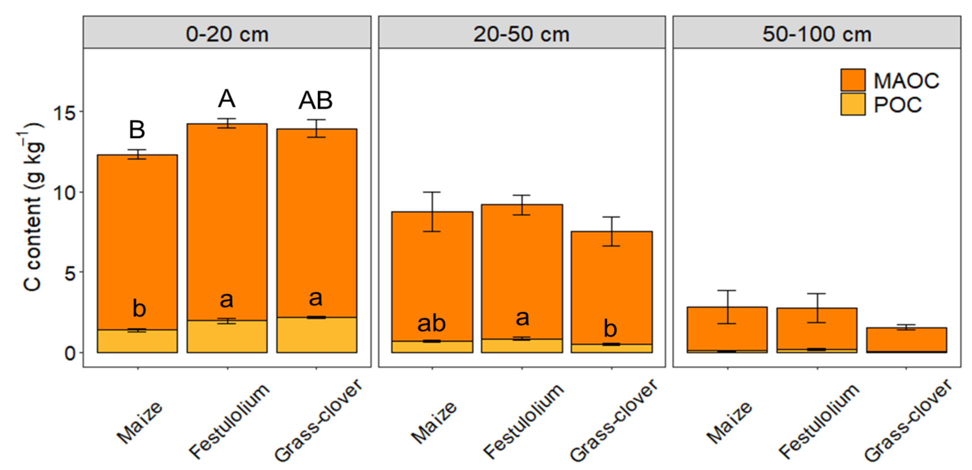
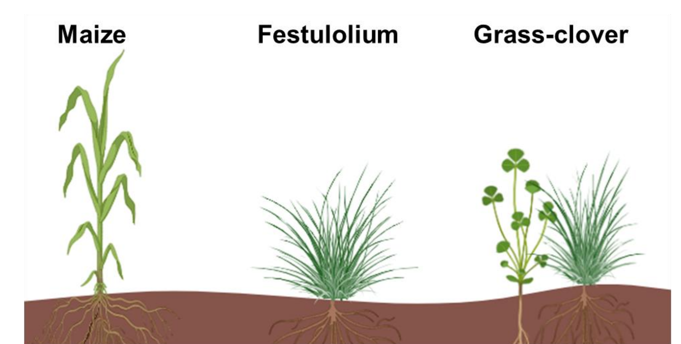


Fig. 1 Soil POC and MAOC content (g kg^{-1} soil) of different cropping systems in 2023 for different depths.

2. Higher root biomass but no higher lignin phenols C in perennial cropping systems. Across the 0–100 cm soil profile, festulolium (6.38 Mg ha^{-1}) and grass-clover (4.09 Mg ha^{-1}) had significantly higher root biomass than maize (1.85 Mg ha^{-1}). In addition, grass-clover had a significantly lower root C/N ratio than maize and festulolium.



Depth (cm)	Maize	Festulolium	Grass-clover
	Root biomass (Mg ha^{-1})		
0–20	1.3 ± 0.2 b	4.86 ± 1.0 a	2.9 ± 0.04 a
20–50	0.4 ± 0.1 b	1.2 ± 0.3 a	0.9 ± 0.1 ab
50–100	0.1 ± 0.03	0.4 ± 0.2	0.3 ± 0.1
C/N	33.9 ± 2.5 a	33.0 ± 2.4 a	24.3 ± 0.5 b

There were no significant differences in lignin phenols C content between cropping systems in POM and MAOM fractions 0–20 cm (Fig. 2). Lignin phenols in POM and MAOM fractions under maize had higher degrees of microbial alteration and oxidation, but with a lower microbial transformation, compared to that under grass-clover.

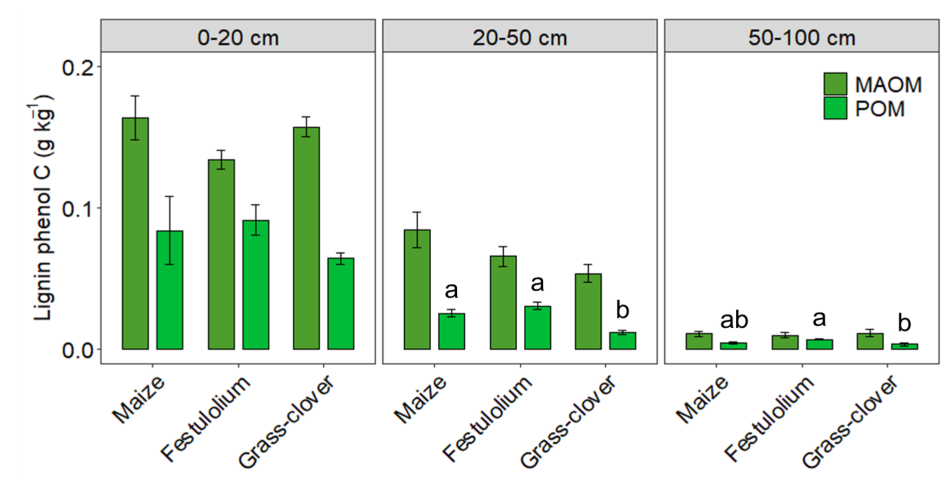


Fig. 2 Lignin phenols C content (g kg^{-1} soil) in POM and MAOM fractions under the different cropping systems at different depths.

3. Higher microbial necromass C in POM but lower in MAOM for the perennials. At 0–20 cm, grass-clover (0.72 mg g^{-1}) had significantly higher fungal and bacterial necromass C content in POM than maize (0.39 mg g^{-1}) (Fig. 3a). In contrast, maize showed significantly higher fungal necromass C content than grass-clover in MAOM (Fig. 3b). Most microbial necromass C (89% in POM and 81% in MAOM) was from fungi.

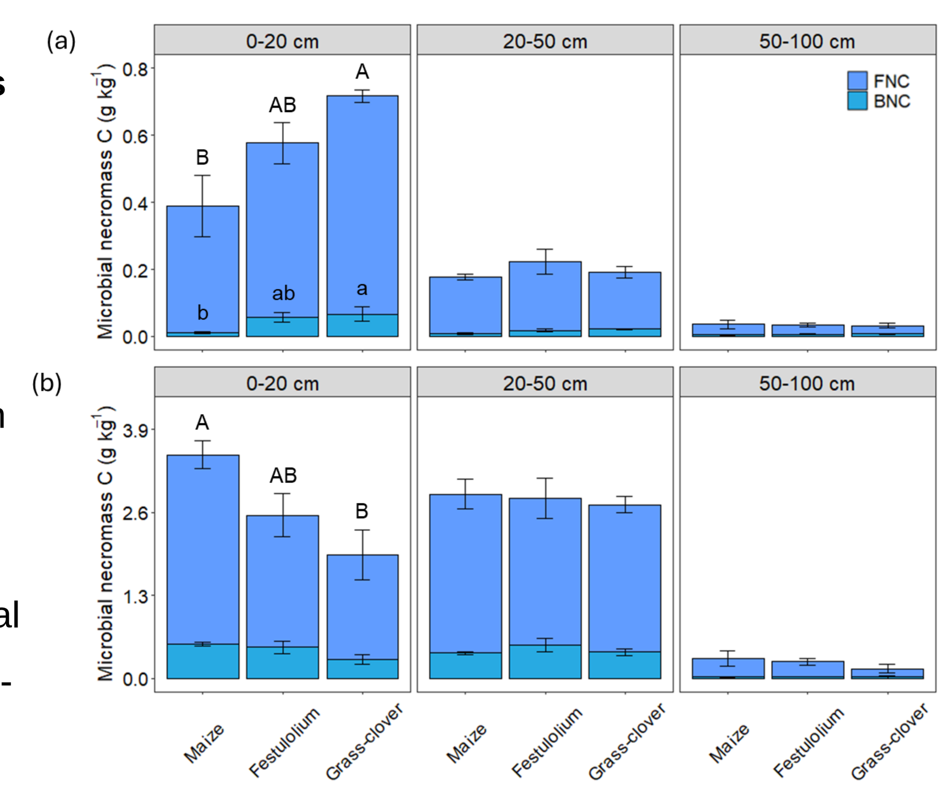
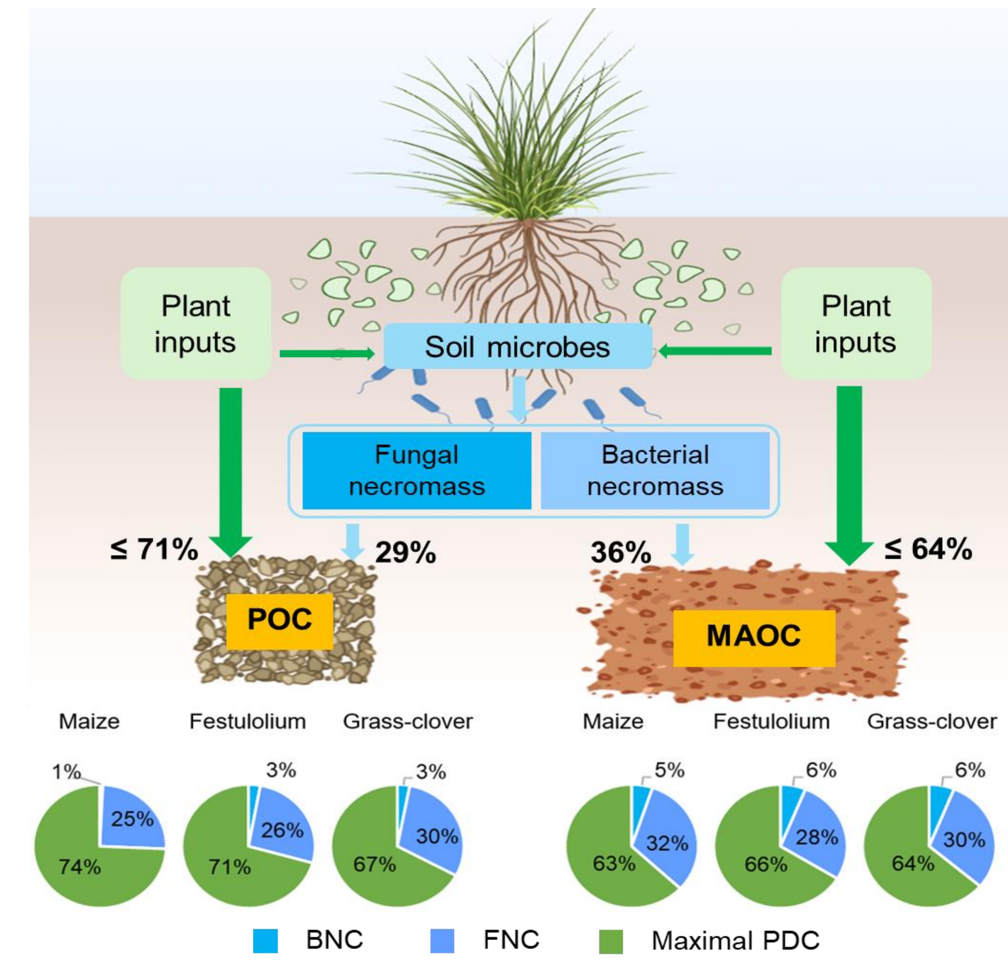


Fig. 3 Fungal (FNC) and bacterial necromass C (BNC) content (g kg^{-1} soil) in the POM (a) and MAOM (b) fractions.

4. Dominance of plant-derived C in POC and MAOC. Microbial necromass C only accounted for 29% of POC at 0–20 cm across the three cropping systems. Consequently, the maximal contribution of plant-derived C to POC was up to 71%. Similarly, soil MAOC was not dominated by microbial necromass C, with the maximal contribution of plant-derived C up to 64% at 0–20 cm.

However, lignin phenols C only contributed to 3% of POC and 0.3% of MAOC, leaving the rest of the C that could originate from plant-derived lipids, neutral sugars, other small molecular root exudates (which can directly adsorb to soil minerals), and pyrogenic C.



Conclusion and Future directions

Our study quantified the differences in POC and MAOC, and the contribution of plant- and microbial-derived C to POC and MAOC in perennial and annual cropping systems. The two perennial cropping systems had higher POC and MAOC in the topsoil than those under maize. Topsoil under perennial cropping systems did not show higher lignin phenol contents but had higher microbial necromass C in POC. Across the three cropping systems, both POC and MAOC were dominated by plant-derived C, indicating that the contribution of microbial-derived C might be overestimated for the cropping systems in cold climates.

Future studies can combine isotope labeling techniques with the quantification of multiple biomarkers, with a particular focus on rhizodeposition, and conduct experiments under different climatic and soil conditions to better understand the mechanisms of C accumulation and stabilization under perennial cropping systems.

Acknowledgement

This study is financially supported by Independent Research Fund Denmark (DFF). The first author was supported by the China Scholarship Council and Frands Christian Frantsen's Scholarship.

Reference

Shang, Y., Olesen, J. E., Lærke, P. E., Manevski, K., & Chen, J. (2024). Perennial cropping systems increased topsoil carbon and nitrogen stocks over annual systems—a nine-year field study. Agriculture, Ecosystems & Environment, 365.

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