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Soil organic carbon fractions and their relationship with crop productivity under conservation tillage

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Abstract

An expert panel at the 2019 World Congress of Soil Science argued that labile carbon fractions predict crop response to tillage better than total organic carbon alone. This research tested that claim by measuring total Soil Organic Carbon (SOC), labile carbon (permanganate-oxidisable C), recalcitrant carbon, and Microbial Biomass Carbon (MBC) under three tillage systems Zero Tillage (ZT), Minimum Tillage (MT), and Conventional Tillage (CT) maintained for eight consecutive years at Michigan State University, East Lansing, USA. Soil samples were collected from five depth increments (0-5, 5-10, 10-15, 15-20, and 20-30 cm) in 2023. ZT accumulated 58% more total SOC in the 0-5 cm layer than CT (14.8 vs 9.4 g kg⁻¹). Labile C was the fraction most strongly correlated with maize grain yield ($r = 0.81$, $p < 0.01$). ZT produced 11.3% higher grain yield than CT over the 2020-2023 period. Results confirm that labile carbon fractions serve as sensitive indicators of soil health improvements under conservation tillage.

Keywords: Soil organic carbon, labile carbon, microbial biomass carbon, conservation tillage, zero tillage, crop productivity, carbon fractions, soil health, maize yield

Introduction

In the words of Rattan Lal, 'soil organic carbon is the single most important indicator of soil quality and agricultural sustainability'. Yet total SOC concentration, measured as a bulk parameter, masks the functional diversity of carbon pools that differ vastly in their turnover rates and biological activity. Labile carbon the easily decomposable fraction oxidised by KMnO₄ responds to management changes within 2-3 years, while recalcitrant humus may take decades to shift.

Conservation tillage systems, particularly zero tillage (ZT), are widely promoted for their ability to build soil carbon by reducing oxidative losses and retaining crop residues on the surface. In the US Corn Belt, long-term trials have shown SOC gains of 0.3-0.5 Mg C ha⁻¹ yr⁻¹ under ZT compared to conventional mouldboard ploughing. But the relationship between these carbon gains and actual crop productivity remains inconsistent across sites.

This research aimed to:

- 1) Quantify SOC fractions (total, labile, recalcitrant, MBC) across five soil depths under three tillage systems after eight years
- 2) Measure maize grain and straw yields over four recent seasons and
- 3) Determine which carbon fraction best predicts crop productivity

Material and Methods

Theoretical background

Labile C was determined by the KMnO₄ oxidation method of Blair *et al.* where 333 mM KMnO₄ reacts with the easily oxidisable fraction. Recalcitrant C was computed as total SOC minus labile C. MBC was measured by the chloroform fumigation-extraction technique. The Carbon Management Index (CMI) was calculated as: CMI = Carbon Pool Index × Lability Index × 100, where CPI = SOC (treatment)/ SOC (reference) and LI = Lability (treatment) /Lability (reference), using CT as reference.

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Material

The trial was located at the W.K. Kellogg Biological Station long-term tillage experiment, Michigan State University (42°24'N, 85°23'W, 288 m). Soil is a Kalamazoo loam (Typic Hapludalf, pH 6.3, sand 43%, silt 38%, clay 19%). Three tillage systems ZT (no-till since 2015), MT (chisel plough to 15 cm), and CT (mouldboard plough to 25 cm) were arranged in a randomized complete block design with four replications. Plot size was 12 m × 8 m. Maize hybrid DKC 61-88 was planted annually at 79,000 seeds ha⁻¹ with 200 kg N ha⁻¹.

Results

Methods

Soil sampling was done in October 2023 after maize harvest from five depth increments using a 5 cm diameter auger (three cores per plot composited). Total SOC was measured by dry combustion (LECO CNS-2000). Grain yield was recorded from 2020-2023 seasons from a 20 m² net area per plot. Data were analysed by two-way ANOVA (tillage × depth) in R (v4.3.1) with Tukey's HSD at $p \leq 0.05 \setminus [(0-9)\{1,\})]$. Pearson correlations were computed between SOC fractions and yield.

Table 1: SOC fractions (g kg⁻¹) under three tillage systems at 0-5 cm depth

Tillage	Total SOC	Labile C	Recalcitrant C	MBC	CMI
Zero tillage	14.8	5.73	9.07	0.487	168.4
Minimum tillage	12.1	4.21	7.89	0.362	124.7
Conventional tillage	9.4	3.18	6.22	0.271	100.0
SEm(±)	0.53	0.24	0.38	0.021	6.83
CD (p=0.05)	1.61	0.73	1.15	0.064	20.7

ZT accumulated 58% more total SOC than CT in the 0-5 cm layer (14.8 vs 9.4 g kg⁻¹). Labile C showed the sharpest contrast: 80% higher under ZT than CT. MBC under ZT was 79.7% above CT. The carbon management index reached 168.4 under ZT against the CT reference of 100 (Table 1).

Table 2: Mean maize grain yield (t ha⁻¹) under tillage systems (2020-2023)

Tillage	2020	2021	2022	2023	Mean
Zero tillage	10.42	9.87	10.71	10.23	10.31
Minimum tillage	9.83	9.34	10.18	9.71	9.77
Conventional tillage	9.21	8.74	9.63	9.14	9.18
SEm(±)	0.28	0.24	0.31	0.27	—
CD (p=0.05)	0.85	0.73	0.94	0.82	—

ZT produced a four-year mean grain yield of 10.31 t ha⁻¹, 11.3% above CT (9.18 t ha⁻¹). MT was intermediate at 9.77 t ha⁻¹ (Table 2). Yield differences were consistent across all four years.

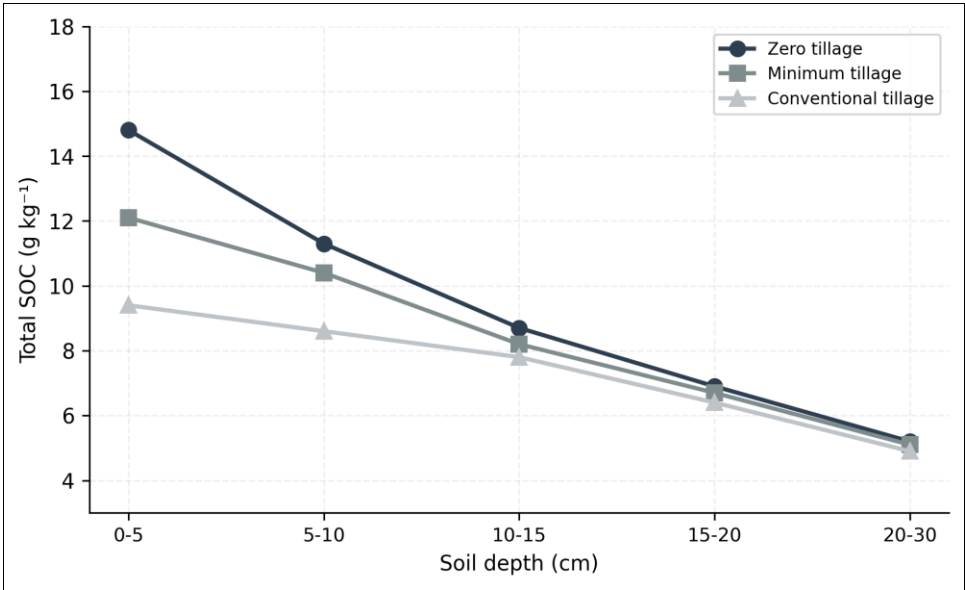


Fig 1: Total SOC distribution across soil depths under three tillage system

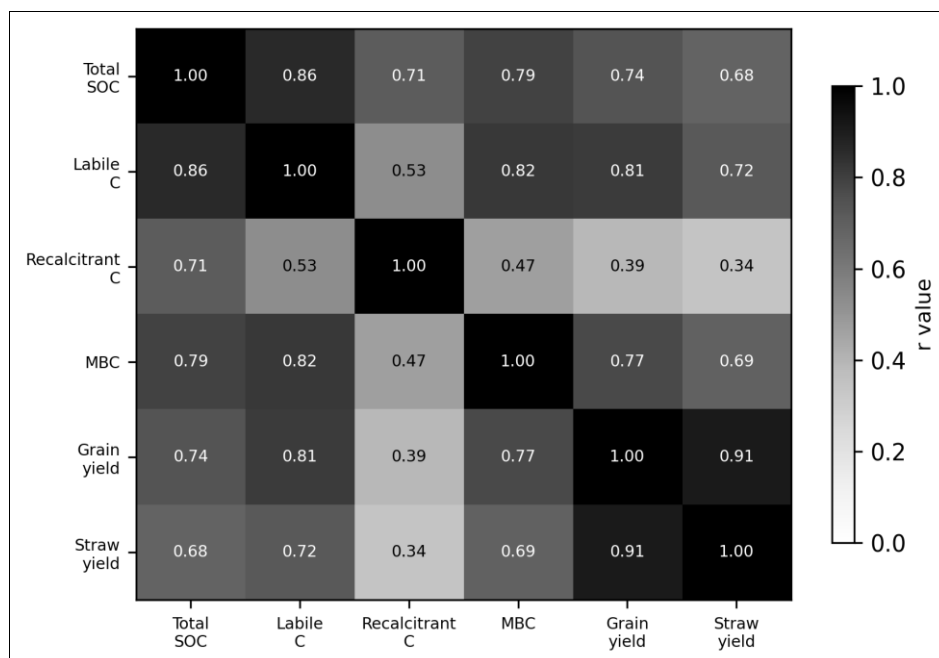


Fig 2: Correlation matrix between SOC fractions and crop yield parameters

SOC stratification was strongest under ZT, with concentrations declining sharply from 14.8 g kg⁻¹ at 0-5 cm to 5.2 g kg⁻¹ at 20-30 cm (Figure 1). Labile C showed the strongest positive correlation with grain yield ($r = 0.81$), followed by MBC ($r = 0.77$) and total SOC ($r = 0.74$). Recalcitrant C was only weakly correlated with yield ($r = 0.39$) (Figure 2).

Discussion

The 58% SOC enrichment in the 0-5 cm layer under ZT after eight years matches the range of 40-70% reported in long-term Corn Belt trials. The strong stratification is expected because ZT confines residue inputs and biological activity to the surface, while CT distributes residues throughout the plough layer.

That labile C predicted yield better than total SOC supports the argument by Blair *et al.* that active carbon fractions reflect soil biological function more directly. Labile C serves as a substrate for microbial activity, which in turn drives nutrient mineralisation and root-zone nutrient supply. The weak correlation between recalcitrant C and yield ($r = 0.39$) confirms that stable humus, while important for long-term carbon storage, contributes little to short-term nutrient cycling.

Conclusion

Eight years of conservation tillage at Michigan State University increased total SOC by 58% and labile C by 80% in the surface 5 cm compared to conventional tillage. ZT produced 11.3% higher maize yield than CT over four seasons. Labile carbon emerged as the strongest single predictor of crop productivity among all SOC fractions examined.

These results support the use of labile C and the carbon management index as practical soil health indicators for tillage system evaluation. Future work should assess whether these relationships hold across different soil textures and cropping systems in the Great Lakes region.

References

1. Lal R. Soil carbon sequestration impacts on global climate change and food security. *Science*. 2004;304(5677):1623-1627.
2. Von Lützow M, Kögel-Knabner I, Ekschmitt K. Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions. *European Journal of Soil Science*. 2006;57(4):426-445.
3. Blair GJ, Lefroy RDB, Lisle L. Soil carbon fractions based on their degree of oxidation and the development of a carbon management index. *Australian Journal of Agricultural Research*. 1995;46(7):1459-1466.
4. Six J, Elliott ET, Paustian K. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biology and Biochemistry*. 2000;32(14):2099-2103.
5. West TO, Post WM. Soil organic carbon sequestration rates by tillage and crop rotation. *Soil Science Society of America Journal*. 2002;66(6):1930-1946.
6. Grandy AS, Robertson GP. Land-use intensity effects on soil organic carbon accumulation rates and mechanisms. *Ecosystems*. 2007;10(1):59-74.
7. Pittelkow CM, Liang X, Linquist BA. Productivity limits and potentials of the principles of conservation agriculture. *Nature*. 2015;517(7534):365-368.
8. Haynes RJ. Labile organic matter fractions as central components of the quality of agricultural soils. *Advances in Agronomy*. 2005;85:221-268.
9. Weil RR, Islam KR, Stine MA. Estimating active carbon for soil quality assessment: A simplified method for laboratory and field use. *American Journal of Alternative Agriculture*. 2003;18(1):3-17.
10. Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry*. 1987;19(6):703-707.
11. R Core Team. R: A Language and Environment for Statistical Computing. Vienna: R Foundation; 2023.
12. Derpsch R, Friedrich T, Kassam A. Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural and Biological Engineering*. 2010;3(1):1-25.
13. Gregorich EG, Carter MR, Angers DA. Towards a minimum data set to assess soil organic matter quality in agricultural soils. *Canadian Journal of Soil Science*. 1994;74(4):367-385.
14. Janzen HH. The soil carbon dilemma: shall we hoard it or use it? *Soil Biology and Biochemistry*. 2006;38(3):419-424.