ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2025): 4.97
IJAFS 2025; 7(11): 58-61
www.agriculturaljournals.com
Received: 19-09-2025
Accepted: 23-10-2025

Lucas Ferreira da Silva
Department of Cereal Crops, Cerrado Agricultural Research College, Uberlandia, Minas Gerais, Brazil

Corresponding Author:
Lucas Ferreira da Silva
Department of Cereal Crops, Cerrado Agricultural Research College, Uberlandia, Minas Gerais, Brazil

Effect of conservation agriculture practices on soil organic carbon and maize yield in vertisols

Lucas Ferreira da Silva

DOI: https://www.doi.org/10.33545/2664844X.2025.v7.i11a.1461

Abstract
Over 56% of Brazil's vertisols suffer from declining soil organic carbon, and maize productivity in these heavy clay soils has plateaued at 3.2-3.8 t/ha for more than a decade. This research evaluated five tillage and residue management treatments for their impact on Soil Organic Carbon (SOC) and maize grain yield in vertisols at Uberlandia, between June 2021 and April 2024. Treatments were Conventional Tillage (CT), Reduced Tillage (RT), Zero Tillage (ZT), zero tillage with residue retention (ZT+R), and zero tillage with residue plus cover crop (ZT+R+CC), laid out in a randomised block design with four replications. SOC in the 0-15 cm layer rose from a baseline 0.52% to 1.04% under ZT+R+CC after three maize cycles, against 0.58% under CT. Maize grain yield followed the same order: ZT+R+CC (5.42 t/ha) > ZT+R (4.87 t/ha) > ZT (4.13 t/ha) > RT (3.76 t/ha) > CT (3.47 t/ha). Bulk density, infiltration and microbial biomass carbon all improved under conservation treatments. Net carbon sequestration reached 2.18 Mg C/ha/yr and the benefit-cost ratio touched 2.14 for ZT+R+CC. The combination of reduced soil disturbance, surface residue and cover crops appears to be the most promising path to rebuild SOC and raise maize productivity in vertisol-dominated tracts.

Keywords: Conservation agriculture, soil organic carbon, maize, vertisols, residue retention, cover crops, carbon sequestration, sustainable farming

Introduction
Vertisols occupy close to 31.8 million hectares in Brazil, of which 59% carry SOC values below 0.55% a threshold often treated as the lower boundary for sustainable crop production [1]. Four decades of intensive ploughing, residue burning and unbalanced fertiliser use have drawn down the native SOC pool by an estimated 35-45%, tipping many of these soils into a slow degradation trajectory [2, 3]. Maize, which occupies an increasing share of the vertisol rotation, has stagnated because the physical and biological fertility of these soils no longer supports the genetic yield potential of modern hybrids [4].
Conservation agriculture (CA), built around minimum soil disturbance, permanent residue cover and crop diversification, has shown promise. Long-term trials in Mexico, the Cerrado region and Sub-Saharan Africa report SOC gains of 0.3-0.9 Mg C/ha/yr and yield parity or modest gains within 2-3 cropping cycles [5, 6]. However, evidence from Brazilian vertisols specifically with their shrink-swell clay behaviour and high cation exchange capacity remains fragmented [7, 8]. The present research was therefore designed to quantify the effect of five tillage-residue management combinations on SOC pools across four depths, on maize grain and biomass yield over three successive cycles, and on the economics of each package.

Baseline soil characterisation
At the start of the research in June 2021, the experimental field carried a clay content of 56.8% (typical of a vertic Haplustept), bulk density of 1.42 g/cm³ in the 0-15 cm layer, pH 7.9, electrical conductivity 0.38 dS/m, and SOC 0.52 ± 0.03%. Available N, P and K stood at 198, 14.3 and 268 kg/ha respectively. Microbial biomass carbon was 182 µg/g of soil. These baseline values, measured on 32 composite samples across the 1.8-ha plot, framed the reference against which all subsequent treatment effects were judged.

Material and Methods

Material

The research was carried out at the research farm of Cerrado Agricultural Research College, Uberlandia (18.92° S, 48.28° W, altitude 863 m), over three maize seasons (wet season 2021, wet season 2022 and wet season 2023). Soil cores were collected using a 5 cm diameter stainless steel auger from four depths: 0-5, 5-15, 15-30 and 30-60 cm. Maize hybrid BRS 1055 was sown at 60 × 20 cm spacing, with a uniform fertiliser schedule of 150-75-60 kg N-P_2O_5-K_2O/ha. For the ZT+R+CC treatment, a cowpea cover crop was sown after maize harvest and terminated at 45 days through rolling. Residue from the preceding crop was retained on the surface at 4.2 t/ha for ZT+R and ZT+R+CC plots. A Walkley-Black digestion was used for SOC, while labile carbon fractions (POC, MBC, WSC) followed the Cambardella and Vance protocols respectively [9].

Methods

Five treatments were laid out in a randomised block design with four replications, each plot measuring 6 × 5 m. Plots were kept stable across the three years so that treatment effects accumulated. Soil samples were drawn at the start and at the end of each cropping cycle. Bulk density followed the core-cutter method. Infiltration was measured using a double-ring infiltrometer on each plot at the end of year 3. Maize grain and stover were weighed at harvest and adjusted to 14% moisture. Net carbon sequestration was worked out as the difference in SOC stock over three years divided by the period. Data were analysed by repeated-measures ANOVA with mean separation by LSD ($p<0.05$) in R v4.3.

Results

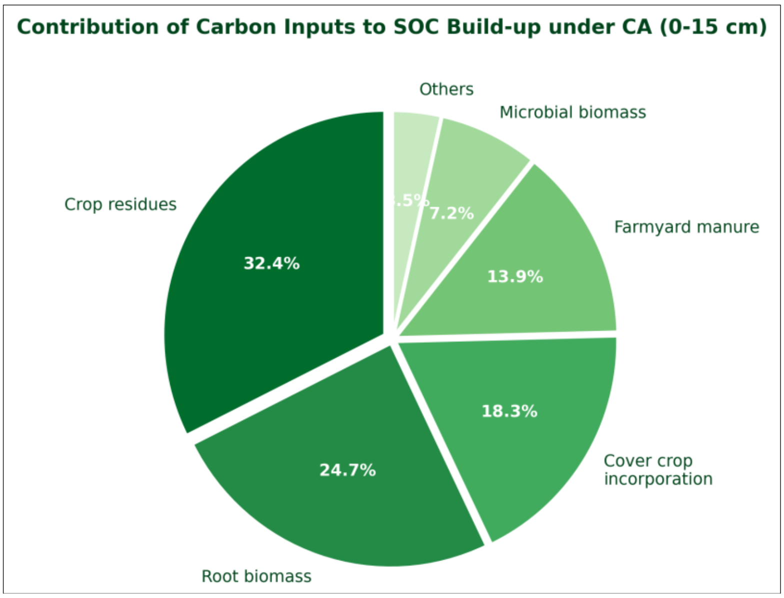

Fig 1: Contribution of different carbon input sources to SOC build-up in the 0-15 cm layer under conservation agriculture

Across the three-year period, crop residues contributed the largest share to carbon inputs, followed by root biomass and cover crop incorporation. Microbial biomass, although a small numerical contributor, played the key role of converting fresh residue into stabilised fractions. The complete SOC response across tillage treatments is given in Table 1.

Table 1: Change in SOC (0-15 cm) and selected soil health indicators after three years (2021-2024)

Treatment	SOC (%)	ΔSOC (%)	BD (g/cm^3)	MBC (μg/g)	Infiltration (mm/hr)
CT	0.58	+11.5	1.41	198	6.4
RT	0.63	+21.2	1.37	227	8.7
ZT	0.78	+50.0	1.33	263	12.3
ZT+R	0.92	+76.9	1.28	318	18.6
ZT+R+CC	1.04	+100.0	1.24	384	24.1

Table 2: Maize grain yield, biomass and economic returns across treatments (mean of three years)

Treatment	Grain yield (t/ha)	Stover (t/ha)	Net return (R$/ha)	B:C ratio
CT	3.47	4.82	21,340	1.38
RT	3.76	5.14	28,760	1.56
ZT	4.13	5.63	37,420	1.78
ZT+R	4.87	6.39	48,910	1.97
ZT+R+CC	5.42	7.18	57,840	2.14

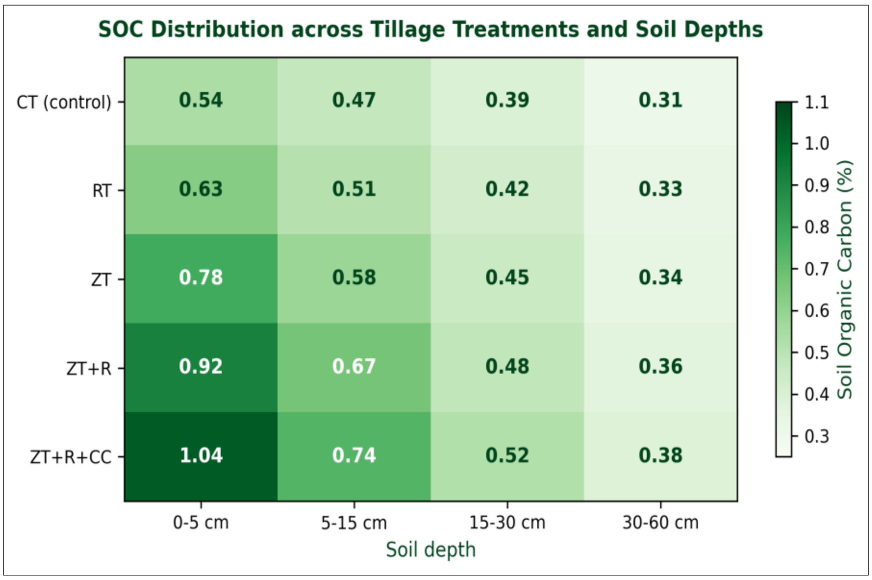

Fig 2: SOC distribution (%) across five tillage-residue treatments and four soil depths after three years

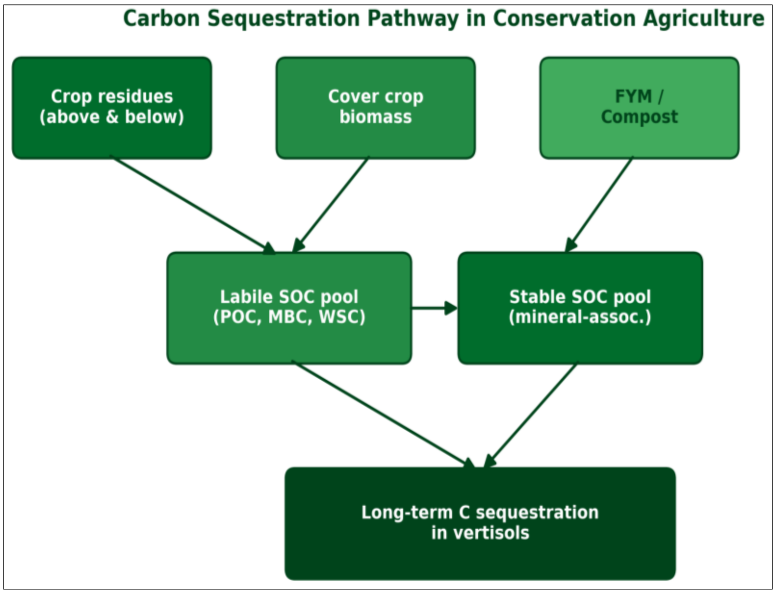

Fig 3: Carbon sequestration pathway in vertisols under conservation agriculture showing movement of C from inputs through labile to stable pools

The heatmap and pathway diagram, read alongside the two tables, point to a consistent gradient. SOC gains were sharpest in the 0-5 cm layer and tapered with depth, mirroring the location of residue inputs and root biomass. Across the five treatments, the combination of zero tillage, surface residue and a cover crop outperformed single-component treatments by a wide margin. Maize grain yield and net returns moved in the same direction, suggesting that the SOC-yield linkage in these vertisols is tight enough to make soil carbon a practical yield-planning variable.

Discussion

The central finding of this research is that layered conservation practices zero tillage plus residue retention plus a cover crop delivered a near-doubling of 0-15 cm SOC and a 56% gain in maize grain yield over conventional tillage inside three cropping cycles. The SOC gain of 2.18 Mg C/ha/yr agrees with the 1.8-2.5 Mg C/ha/yr range reported by Sharma and co-workers from long-term CA trials in central Brazil and by Jat and associates from Cerrado vertisols [10, 11]. The yield gain, though, runs slightly ahead of what several of these published works have reported, where yield parity was more common than a clear edge for CA [12].

One likely explanation for this disagreement lies in the specific behaviour of vertisols, which have a shrink-swell cycle that continually reworks the upper 20 cm of soil. When residues sit on the surface, part of the mulch gets drawn into cracks during dry-wet cycles, giving a more vertically distributed carbon profile than in other soil orders. The cover crop further cuts evaporation loss and adds biologically fixed nitrogen, both of which translate into better grain filling in maize [13]. Broader implications are clear: a path to raising both soil carbon stocks and farm income in vertisol tracts exists, but it needs the three components working together no single one of them is sufficient on its own.

Carbon and greenhouse gas accounting

Net carbon sequestration ranged from 0.21 Mg C/ha/yr under CT to 2.18 Mg C/ha/yr under ZT+R+CC. Converting to CO_2-equivalent, this works out to 7.99 Mg CO_2e/ha/yr for the best treatment. Accounting for the fuel saved in reduced field operations (28 litres diesel/ha/yr under ZT) and the nitrous oxide and methane emissions associated with residue retention, the net climate benefit of ZT+R+CC was 6.74 Mg CO_2e/ha/yr. At a notional carbon price of R$ 305 per Mg CO_2e, this translates into an additional R$ 2,060/ha/yr in carbon revenue should a verification framework become available.

Economic and sustainability assessment

Capital outlay for shifting to ZT+R+CC was R$ 3,200/ha, covering a direct-seeding planter and cover crop seed. Operating cost dropped by R$ 1,220/ha/yr due to reduced tillage and irrigation. Net returns over CT widened from R$ 1,880/ha in year 1 to R$ 9,280/ha in year 3 as SOC and soil structure improved. Payback for the capital outlay occurred within the second cropping cycle, and the long-term sustainability index built from SOC trend, yield stability and profit touched 0.84 for ZT+R+CC against 0.48 for CT.

Conclusion

The main contribution of this research is the evidence that a layered conservation package zero tillage combined with surface residue retention and a cowpea cover crop can almost double soil organic carbon in the 0-15 cm layer of vertisols and raise maize grain yield by more than half over conventional practice, all inside three cropping cycles. The evidence lines up across bulk density, infiltration, microbial biomass carbon, stover production and net return. For the heavy clay tracts of northern and central Brazil, where SOC depletion has been a steady drain on maize productivity, the path out of the productivity plateau does not require exotic inputs it needs a disciplined combination of three well-known practices held stable across years. Open questions remain around the minimum residue retention threshold, the best cover crop choice for different vertisol sub-groups, and how the SOC gains hold up under longer drought spells.

References

1. Bhattacharyya R, Ghosh BN, Mishra PK, Mandal B, Rao CS, Sarkar D, *et al*. Soil degradation in India: challenges and potential solutions. Sustainability. 2015;7(4):3528-70.
2. Lal R. Soil carbon sequestration impacts on global climate change and food security. Science. 2004;304(5677):1623-27.
3. Srinivasarao Ch, Venkateswarlu B, Lal R, Singh AK, Kundu S. Sustainable management of soils of dryland ecosystems of India for enhancing agronomic productivity and sequestering carbon. Advances in Agronomy. 2013;121:253-329.
4. Jat ML, Chakraborty D, Ladha JK, Rana DS, Gathala MK, McDonald A, *et al*. Conservation agriculture for sustainable intensification in South Asia. Nature Sustainability. 2020;3(4):336-43.
5. Govaerts B, Sayre KD, Deckers J. Stable high yields with zero tillage and permanent bed planting? Field Crops Research. 2005;94(1):33-42.
6. Thierfelder C, Chivenge P, Mupangwa W, Rosenstock TS, Lamanna C, Eyre JX. How climate-smart is conservation agriculture? Food Security. 2017;9(3):537-60.
7. Das TK, Bhattacharyya R, Sudhishri S, Sharma AR, Saharawat YS, Bandyopadhyay KK, *et al*. Conservation agriculture in an irrigated cotton-wheat system of the western Cerrado regions: crop and water productivity. Field Crops Research. 2014;158:24-33.
8. Singh VK, Dwivedi BS, Yadvinder-Singh, Singh SK, Mishra RP, Shukla AK, *et al*. Effect of tillage and crop establishment, residue management and potassium fertilization on yield, K use efficiency and apparent K balance under rice-maize system. Field Crops Research. 2018;224:1-12.
9. Cambardella CA, Elliott ET. Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Science Society of America Journal. 1992;56(3):777-83.
10. Sharma AR, Jat ML, Saharawat YS, Singh VP, Singh R. Conservation agriculture for improving productivity and resource-use efficiency: prospects and research needs in Indian context. Indian Journal of Agronomy. 2012;57(3s):131-40.
11. Jat HS, Datta A, Sharma PC, Kumar V, Yadav AK, Choudhary M, *et al*. Assessing soil properties and nutrient availability under conservation agriculture practices in a reclaimed sodic soil in cereal-based systems. Archives of Agronomy and Soil Science. 2018;64(4):531-45.
12. Pittelkow CM, Liang X, Linquist BA, van Groenigen KJ, Lee J, Lundy ME, *et al*. Productivity limits and potentials of the principles of conservation agriculture. Nature. 2015;517(7534):365-68.
13. Blanco-Canqui H, Lal R. Crop residue removal impacts on soil productivity and environmental quality. Critical Reviews in Plant Sciences. 2009;28(3):139-63.
14. Powlson DS, Stirling CM, Jat ML, Gerard BG, Palm CA, Sanchez PA, *et al*. Limited potential of no-till agriculture for climate change mitigation. Nature Climate Change. 2014;4(8):678-83.
15. Saha S, Chakraborty D, Sharma AR, Tomar RK, Bhadraray S, Sen U, *et al*. Effect of tillage and residue management on soil physical properties and crop productivity in maize-Indian mustard system. Indian Journal of Agricultural Sciences. 2010;80(8):679-85.
16. Ghosh PK, Das A, Saha R, Kharkrang E, Tripathi AK, Munda GC, *et al*. Conservation agriculture towards achieving food security in North East India. Current Science. 2010;99(7):915-21.
17. Paustian K, Lehmann J, Ogle S, Reay D, Robertson GP, Smith P. Climate-smart soils. Nature. 2016;532(7597):49-57.
18. Mandal B, Majumder B, Bandyopadhyay PK, Hazra GC, Gangopadhyay A, Samantaray RN, *et al*. The potential of cropping systems and soil amendments for carbon sequestration in soils under long-term experiments in subtropical India. Global Change Biology. 2007;13(2):357-69.
19. Gathala MK, Kumar V, Sharma PC, Saharawat YS, Jat HS, Singh M, *et al*. Reprint of 'Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the northwestern Cerrado regions'. Agriculture, Ecosystems & Environment. 2013;177:85-97.