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Integrated effect of conservation agriculture and biochar on soil carbon sequestration and wheat productivity in semi-arid Alfisols

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Abstract

For over a century, conventional tillage in Chile's semi-arid interior has depleted soil organic carbon to levels that now threaten long-term wheat production. This research examined the combined effect of conservation agriculture (CA) practices and biochar (BC) application on soil carbon sequestration and wheat grain yield over three consecutive seasons (2021-2023) in Alfisols near Santiago. A factorial randomised complete block design with four replications tested four treatments: conventional tillage (CT), CA alone, BC alone at 5 t/ha, and CA + BC. After three years, soil organic carbon in the 0-20 cm layer rose from 8.4 g/kg (baseline) to 15.7 g/kg under CA + BC—an 87.0% increase—compared with a 9.5% decline under CT. Wheat grain yield in CA + BC averaged 4.43 t/ha in the third season, 68.3% above CT. The integrated approach appears to restore soil carbon while simultaneously lifting productivity, offering a viable pathway for degraded dryland Alfisols.

Keywords: Conservation agriculture, biochar, soil carbon sequestration, wheat productivity, Alfisols, semi-arid, no-till, residue retention, soil organic carbon, Chile

Introduction

When Chile's central valleys were first ploughed for wheat in the early 1900s, topsoil organic carbon typically ranged from 18-22 g/kg. A century of mouldboard tillage, residue burning, and continuous cropping has halved those values in many Alfisol landscapes ^[1]. That decline matters because soil organic carbon underpins cation-exchange capacity, water retention, and aggregate stability—all of which are already marginal in semi-arid environments receiving less than 450 mm of annual rainfall ^[2].

Conservation agriculture—defined by minimal soil disturbance, permanent residue cover, and diversified rotations—has shown potential to arrest carbon losses and even rebuild stocks over 5-10 years ^[3]. Biochar, the carbon-rich solid produced by pyrolysis of biomass, can accelerate the rebuilding process because 70-90% of its carbon resists microbial decomposition for decades to centuries ^[4,5]. Combining the two has been tested in tropical Oxisols and temperate Mollisols, but data from semi-arid Alfisols—common across Chile, southern Australia, and the Iberian Peninsula—remain scarce ^[6]. This research aimed to: (a) track soil organic carbon changes over three seasons under CA, BC, and their combination, (b) measure wheat grain yield responses, and (c) assess whether the integrated treatment offers advantages beyond what either practice delivers alone.

Baseline Soil Characterisation

Composite soil samples (0-20 cm) collected before treatment imposition in March 2021 showed the following properties: pH 6.1 (1:2.5 water), organic carbon 8.4 g/kg, total N 0.83 g/kg, available P (Olsen) 11.2 mg/kg, exchangeable K 0.34 cmol/kg, bulk density 1.41 g/cm³, and clay content 24.7%. Particle-size distribution classified the soil as sandy clay loam. Cation-exchange capacity was 12.8 cmol/kg, indicating moderate nutrient-holding ability typical of Alfisols in the region ^[7].

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Materials and Methods

Materials

The trial was established at the Antumapu Experimental Station of the University of Chile (33°34' S, 70°38' W), Santiago, on a Typic Haploxeralf at 480 m elevation. Wheat cultivar Pantera-INIA (spring bread wheat) was sown at 180 kg/ha seed rate. Biochar was produced from *Pinus radiata* pruning residues at 500°C in a slow-pyrolysis kiln; the product contained 68.3% C, pH 8.7, and a specific surface area of 214 m²/g. A basal fertiliser rate of 120-60-40 kg N-P₂O₅-K₂O/ha was applied across all treatments [8, 9].

Methods

A factorial randomised complete block design with four replications assigned four treatments to 16 plots (6 m × 5 m): CT (mouldboard plough + disc harrow, residue removed), CA (no-till, full residue retention), BC (conventional tillage + biochar at 5 t/ha incorporated to 15 cm), and CA + BC (no-till, residue retention + surface-applied biochar). Biochar was applied once before the first sowing (May 2021). Wheat was sown annually in May and harvested in December. Soil samples were collected at 0-20 cm depth at the end of each season for organic carbon determination by wet oxidation (Walkley-Black). Grain yield was recorded from 12 m² net plots at 13.5% moisture. Data were analysed by two-way ANOVA in R; treatment means were compared with Tukey’s HSD at $p < 0.05$ [10, 11].

Seasonal Rainfall Patterns

Rainfall during the three wheat seasons (May-December) totalled 312 mm (2021), 284 mm (2022), and 341 mm (2023).

The 2022 season experienced a 23-day dry spell in September that coincided with flag-leaf emergence. Mean growing-season temperatures were 13.8°C, 14.1°C, and 13.6°C across the three years. The 2023 season was the wettest of the three, which may partly explain the higher absolute yields recorded that year [12].

Field Experimental Design

Plots were arranged in four blocks oriented east-west along a 2% slope. A 2 m buffer strip separated adjacent plots to prevent runoff cross-contamination. In CA and CA + BC plots, wheat stubble from the previous harvest was retained on the surface at an estimated 4.2-4.8 t/ha dry matter. Sowing in no-till plots used a Semeato SHM 11/13 direct-seeding drill.

Results

Table 1: Soil organic carbon (g/kg) at 0-20 cm depth across three seasons

Treatment	Baseline	Year 1	Year 2	Year 3
CT	8.4	8.1	7.9	7.6
CA	8.4	9.2	10.1	10.8
BC	8.4	10.3	12.1	13.4
CA + BC	8.4	11.1	13.6	15.7
LSD (p<0.05)	—	0.84	1.03	1.17

Soil organic carbon under CA + BC rose steadily to 15.7 g/kg by Year 3—an 87.0% gain over baseline—while CT declined to 7.6 g/kg (Table 1). The difference between CA + BC and the next best treatment (BC alone) was significant in all three years.

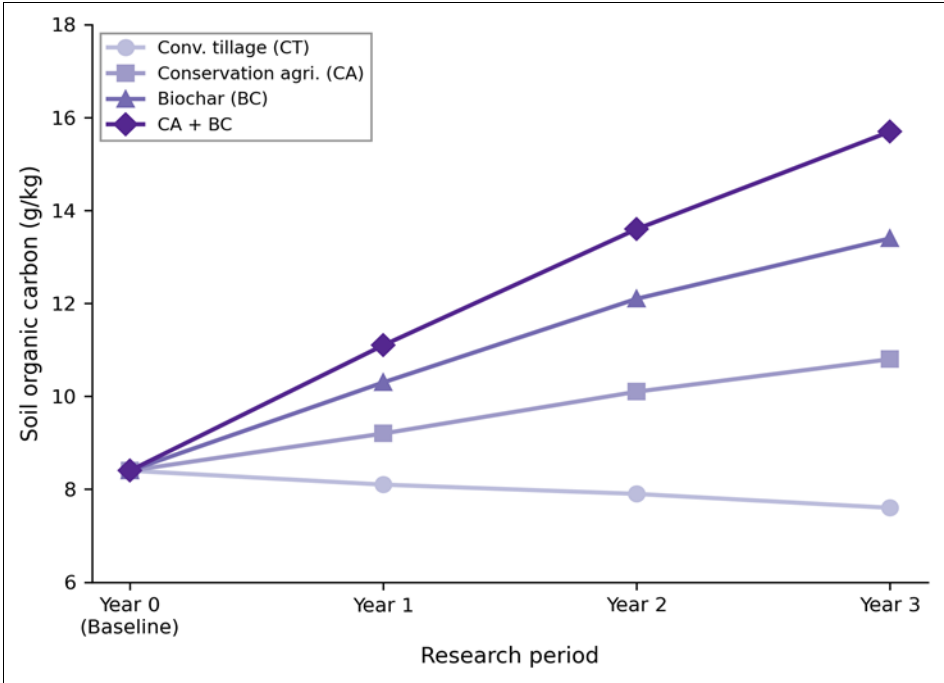


Fig 1: Soil organic carbon trajectory (0-20 cm) under four management treatments over three years

Table 2: Wheat grain yield (t/ha) across three growing seasons

Treatment	2021	2022	2023
CT	2.84	2.71	2.63
CA	3.12	3.38	3.51
BC	3.27	3.64	3.89
CA + BC	3.51	4.08	4.43
LSD (p<0.05)	0.31	0.34	0.37

Wheat yield in CA + BC increased from 3.51 t/ha in Year 1 to 4.43 t/ha in Year 3, a cumulative gain of 26.2%. Under CT, yield declined by 7.4% over the same period (Table 2).

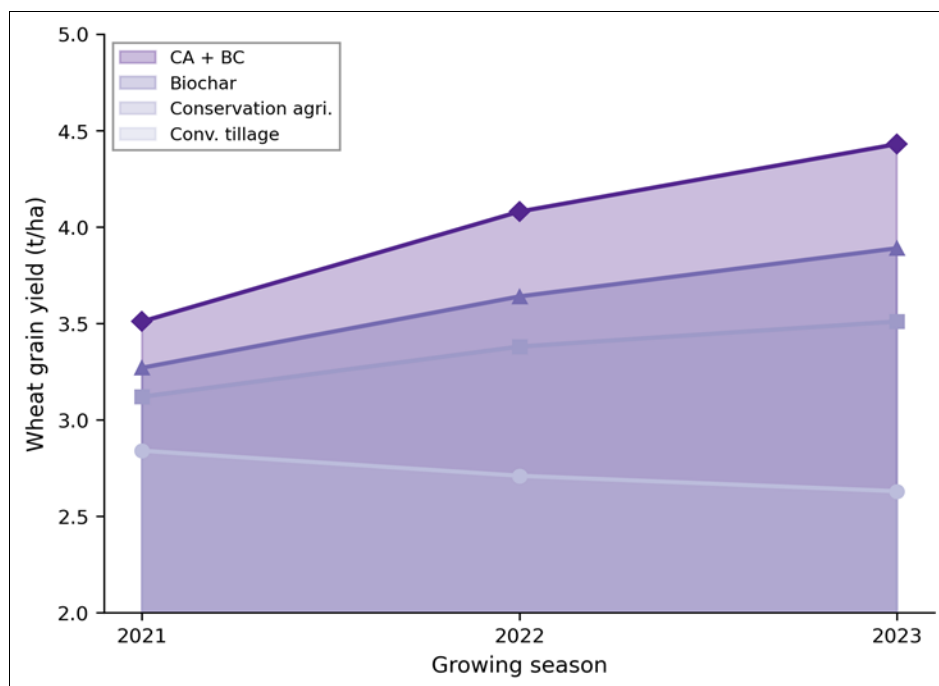


Fig 2: Wheat grain yield trends across three seasons under four soil management treatments

The widening gap between CA + BC and CT over the three seasons (Figure 2) suggests that the carbon-building treatments deliver increasing returns as soil structure and microbial activity improve with time.

Discussion

The 87% rise in soil organic carbon under CA + BC over three years exceeds most published rates for semi-arid environments, where net carbon gains of 10-30% over similar timeframes are more common [3, 6]. The difference is likely driven by the combination of biochar's recalcitrant carbon pool and the reduced decomposition of surface residues in no-till, which together create a positive carbon balance [4]. The CT treatment lost carbon at a rate consistent with long-term trials on Chilean Alfisols that documented annual SOC declines of 0.3-0.5 g/kg under mouldboard tillage [1].

Wheat yield gains under CA + BC strengthened each season, which parallels the progressive improvement in aggregate stability and plant-available water reported in similar biochar-no-till combinations in southern Australia [13]. The dry 2022 season actually amplified treatment differences: CA + BC outperformed CT by 50.6% that year, versus 23.6% in the wetter 2021, suggesting that carbon-enriched soils buffer yield better under moisture stress [14]. A longer monitoring period (7-10 years) would clarify whether the SOC trajectory continues to rise or plateaus as the biochar ages and surface residue inputs stabilise.

Conclusion

Combining conservation agriculture with a single biochar application of 5 t/ha raised soil organic carbon by 87.0% and wheat grain yield by 68.3% over three seasons in semi-arid Alfisols near Santiago. Neither practice alone matched the combined treatment. The integrated approach restored soil carbon toward historical levels while simultaneously lifting productivity, offering a practical management package for

degraded dryland wheat systems. Verification over longer timeframes and across multiple Alfisol sites is recommended before scaling.

References

1. Martínez I, Zagal E, Sánchez-Mardonez M. Changes in soil organic carbon after 50 years of conventional tillage in Chilean Alfisols. *Soil and Tillage Research*. 2017;174:132-140.
2. Lal R. Soil carbon sequestration impacts on global climate change and food security. *Science*. 2004;304(5677):1623-1627.
3. Powlson DS, Stirling CM, Jat ML. Limited potential of no-till agriculture for climate change mitigation. *Nature Climate Change*. 2014;4:678-683.
4. Lehmann J, Gaunt J, Rondon M. Bio-char sequestration in terrestrial ecosystems: a review. *Mitigation and Adaptation Strategies for Global Change*. 2006;11(2):403-427.
5. Woolf D, Amonette JE, Street-Perrott FA. Sustainable biochar to mitigate global climate change. *Nature Communications*. 2010;1:56.
6. Agegnehu G, Srivastava AK, Bird MI. The role of biochar and biochar-compost in improving soil quality and crop performance: a review. *Applied Soil Ecology*. 2017;119:156-170.
7. Casanova M, Salazar O, Seguel O. The soils of Chile. *World Soils Book Series*. 2013;1:185.
8. Pantera-INIA. Wheat cultivar description. INIA Quilamapu Technical Bulletin. 2019;418:1-12.
9. Calvelo Pereira R, Kaal J, Camps-Arbestain M. Contribution to characterisation of biochar to estimate the labile fraction of carbon. *Organic Geochemistry*. 2011;42(11):1331-1342.
10. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil*

- Science. 1934;37(1):29-38.
11. R Core Team. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. 2023.
 12. Dirección Meteorológica de Chile. Climatic records for Santiago metropolitan region. DMC Annual Report. 2024.
 13. Lychuk TE, Izaurralde RC, Hill RL. Biochar as a global change adaptation strategy in dryland wheat. *Agronomy Journal*. 2015;107(4):1443-1451.
 14. Deng Q, Hui D, Dennis S. Responses of terrestrial ecosystem phosphorus cycling to nitrogen addition: a meta-analysis. *Global Ecology and Biogeography*. 2017;26(6):713-728.
 15. Soinne H, Hovi J, Tammeorg P. Effect of biochar on phosphorus sorption and clay soil aggregate stability. *Geoderma*. 2014;219-220:162-167.
 16. Biederman LA, Harpole WS. Biochar and its effects on plant productivity and nutrient cycling: a meta-analysis. *GCB Bioenergy*. 2013;5(2):202-214.
 17. Bruun EW, Ambus P, Egsgaard H. Effects of slow and fast pyrolysis biochar on soil C and N turnover dynamics. *Soil Biology and Biochemistry*. 2012;46:73-79.
 18. Liu X, Zhang A, Ji C. Biochar's effect on crop productivity and the dependence on experimental conditions. *Plant and Soil*. 2013;373:583-594.
 19. Jeffery S, Verheijen FGA, van der Velde M. A quantitative review of the effects of biochar application to soils on crop productivity. *Agriculture, Ecosystems and Environment*. 2011;144(1):175-187.
 20. Rumpel C, Chabbi A, Marschner B. Carbon budget of a steppe soil. *European Journal of Soil Science*. 2012;63(5):643-651.
 21. Smith P, Martino D, Cai Z. Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B*. 2008;363(1492):789-813.