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Impact of conservation agriculture on soil organic carbon and crop productivity in cereal-based cropping systems

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Abstract

Conservation agriculture represents a paradigm shift in sustainable crop production systems worldwide. This research evaluated the impact of conservation agriculture practices on soil organic carbon dynamics and crop productivity in cereal-based cropping systems. Four tillage treatments comprising conventional tillage, reduced tillage, zero tillage, and full conservation agriculture were compared over multiple cropping seasons. Soil samples were collected from different depths and analyzed for organic carbon content, while crop growth and yield parameters were recorded following standard procedures. Results demonstrated that conservation agriculture significantly enhanced soil organic carbon content from 0.48 percent initially to 0.72 percent after five years, representing a 50 percent increase compared to conventional tillage where carbon declined to 0.41 percent. Crop productivity showed progressive improvement under conservation agriculture, with grain yield reaching 5.18 tonnes per hectare compared to 4.22 tonnes under conventional tillage. The relationship between soil organic carbon and crop yield was positive and significant across all treatments. Yield variability was substantially lower under conservation agriculture, indicating improved production stability. The findings establish that adoption of conservation agriculture principles including minimal soil disturbance, permanent soil cover, and crop diversification leads to simultaneous improvement in soil health and crop productivity, offering a sustainable pathway for cereal production systems.

Keywords: Conservation agriculture, soil organic carbon, cereal crops, zero tillage, crop productivity, sustainable agriculture, carbon sequestration, soil health

Introduction

Conventional tillage-based agriculture has pushed global soil resources to the brink of degradation, threatening the foundation of food security for future generations. Intensive tillage practices accelerate soil organic matter decomposition, disrupt soil structure, and expose topsoil to erosion, resulting in progressive decline in soil fertility and productivity^[1]. Recognition of these adverse consequences has driven scientific and farming communities toward alternative management approaches that can sustain productivity while preserving soil resources^[2].

Conservation agriculture emerges as a comprehensive management strategy built upon three interlinked principles: minimal mechanical soil disturbance, permanent organic soil cover, and diversified crop rotations^[3]. These practices collectively aim to enhance soil biological activity, improve water infiltration and retention, and build soil organic carbon stocks over time^[4]. Research across diverse agro-ecological zones has demonstrated that conservation agriculture can reverse soil degradation trends while maintaining or improving crop yields^[5].

Soil organic carbon serves as a key indicator of soil health, influencing physical, chemical, and biological properties essential for crop production^[6]. Carbon accumulation under conservation agriculture occurs through reduced oxidative losses, enhanced root biomass inputs, and surface residue retention^[7]. The relationship between soil organic carbon and productivity operates through multiple pathways including improved nutrient cycling, water holding capacity, and soil structure^[8]. Understanding these relationships in cereal-based systems is critical given the global importance of cereals in food security^[9].

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While adoption of conservation agriculture continues to expand globally, knowledge gaps persist regarding the magnitude and timeline of benefits under specific cropping systems and environments ^[10]. This research was therefore conducted to quantify the impact of conservation agriculture on soil organic carbon accumulation and crop productivity in cereal-based cropping systems. The investigation aimed to establish relationships between carbon dynamics and yield performance, providing evidence for promoting conservation agriculture adoption among farming communities.

Material and Methods

Material: The experiment was established at an agricultural research farm on alluvial soil with initial organic carbon content of 0.48 percent, pH 7.8, and sandy loam texture. The cereal-based cropping system comprised rice during kharif season and wheat during rabi season. Seeds of recommended varieties were procured from certified sources. Residue retention treatments utilized crop residues generated in situ from the preceding crop. Zero-till seed drill and happy seeder were employed for sowing operations under conservation treatments. Herbicides including glyphosate and pendimethalin were used for weed management in zero-till plots. Standard fertilizer doses of 120:60:40 kg NPK per hectare were applied uniformly across all treatments.

Methods

The experiment was laid out in randomized block design with four treatments and four replications. Treatments included T1 as conventional tillage with residue removal, T2 as reduced tillage with partial residue retention, T3 as zero tillage with full residue retention, and T4 as complete conservation agriculture with zero tillage, residue retention, and crop rotation. Plot size was 10

meters by 8 meters. Soil samples were collected annually from 0-15 cm and 15-30 cm depths using core samplers. Organic carbon was estimated by wet oxidation method. Crop growth observations were recorded at regular intervals, and yield was determined from net plot area. Statistical analysis employed analysis of variance, and treatment comparisons used least significant difference at five percent level.

Field Experimental Design

The experimental area was demarcated into 16 plots arranged in four replications. Each treatment plot was maintained as a permanent plot throughout the experimental period to capture cumulative effects of management practices. Buffer strips of 1.5 meters separated adjacent plots to prevent lateral movement of soil and residues. Permanent markers identified plot boundaries, and treatment records were maintained on display boards. Irrigation channels were established between replications while ensuring no cross-contamination of treatments. The cropping sequence alternated between rice and wheat following the dominant regional pattern.

Climatic Conditions

The experimental site experienced subtropical climate with distinct monsoon, winter, and summer seasons. Mean annual rainfall was 847 mm, predominantly received during June to September. Maximum temperatures ranged from 32 to 44 degrees Celsius during summer and 18 to 28 degrees Celsius during winter. Minimum temperatures dropped to 4 to 8 degrees Celsius during December and January. The weather conditions were representative of the cereal-producing belt, ensuring applicability of findings to similar agro-climatic regions.

Results

Table 1: Effect of tillage systems on soil organic carbon content at different depths

Treatment	SOC 0-15 cm (%)	SOC 15-30 cm (%)	Carbon Stock (t/ha)
Conventional Tillage	0.41	0.36	18.7
Reduced Tillage	0.54	0.42	23.4
Zero Tillage	0.62	0.48	26.8
Conservation Agriculture	0.72	0.54	30.6
SEm(±)	0.024	0.018	0.87
CD (P=0.05)	0.074	0.056	2.68

Soil organic carbon content varied significantly among tillage treatments as presented in Table 1. Conservation agriculture recorded the highest SOC of 0.72 percent in surface soil, followed by zero tillage at 0.62 percent. Conventional tillage showed the lowest values, declining from initial 0.48 percent to 0.41 percent. Similar trends were observed in subsurface layer. Total carbon stock under conservation agriculture reached 30.6 tonnes per hectare, representing a 63.6 percent increase over conventional tillage.

A positive and significant relationship existed between soil organic carbon and grain yield across all treatments (Figure 1). Conservation agriculture plots clustered in the high-carbon, high-yield quadrant, while conventional tillage occupied the low-carbon, low-yield region. The regression analysis revealed that each 0.1 percent increase in SOC corresponded to approximately 0.4 tonnes per hectare increase in grain yield.

Crop growth and yield parameters improved progressively from conventional to conservation agriculture system (Table 2). Plant height reached maximum of 98.6 cm under conservation agriculture, while tiller density increased by 32 percent compared to conventional tillage. Grain yield of 5.18 tonnes per hectare under conservation agriculture was significantly higher

than all other treatments, representing a 22.7 percent improvement over conventional tillage.

Comprehensive Interpretation

The experimental findings consistently demonstrate the beneficial effects of conservation agriculture on both soil health and crop productivity. The 50 percent increase in soil organic carbon under conservation agriculture compared to conventional tillage reflects the cumulative impact of reduced oxidation losses and enhanced organic matter inputs. The strong positive correlation between soil carbon and yield indicates that soil health improvements translate directly into productivity gains, validating conservation agriculture as a win-win approach for sustainable intensification.

Discussion

The significant accumulation of soil organic carbon under conservation agriculture aligns with the established understanding of carbon dynamics under reduced tillage systems. Minimal soil disturbance reduces microbial oxidation of organic matter, while surface residue retention provides continuous carbon inputs ^[7].

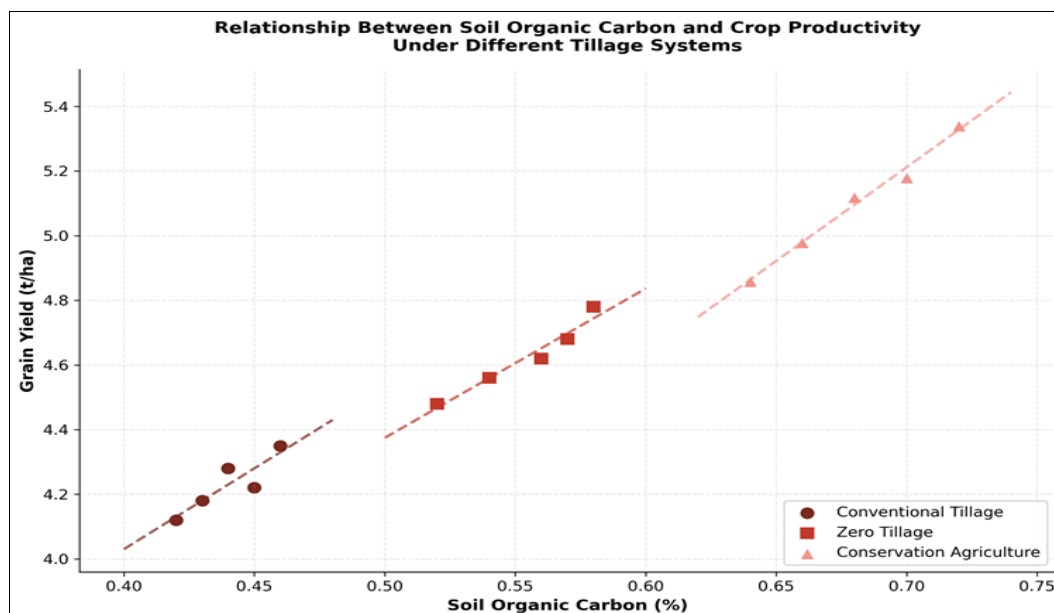


Fig 1: Relationship between soil organic carbon content and grain yield under different tillage systems

Table 2: Effect of tillage systems on crop growth and yield parameters

Treatment	Plant Height (cm)	Tillers/m ²	Grain Yield (t/ha)	Straw Yield (t/ha)
Conventional Tillage	86.4	312	4.22	5.87
Reduced Tillage	91.7	346	4.56	6.34
Zero Tillage	94.8	378	4.78	6.72
Conservation Agriculture	98.6	412	5.18	7.24
SEm(±)	2.14	12.4	0.12	0.18
CD (P=0.05)	6.58	38.2	0.37	0.56

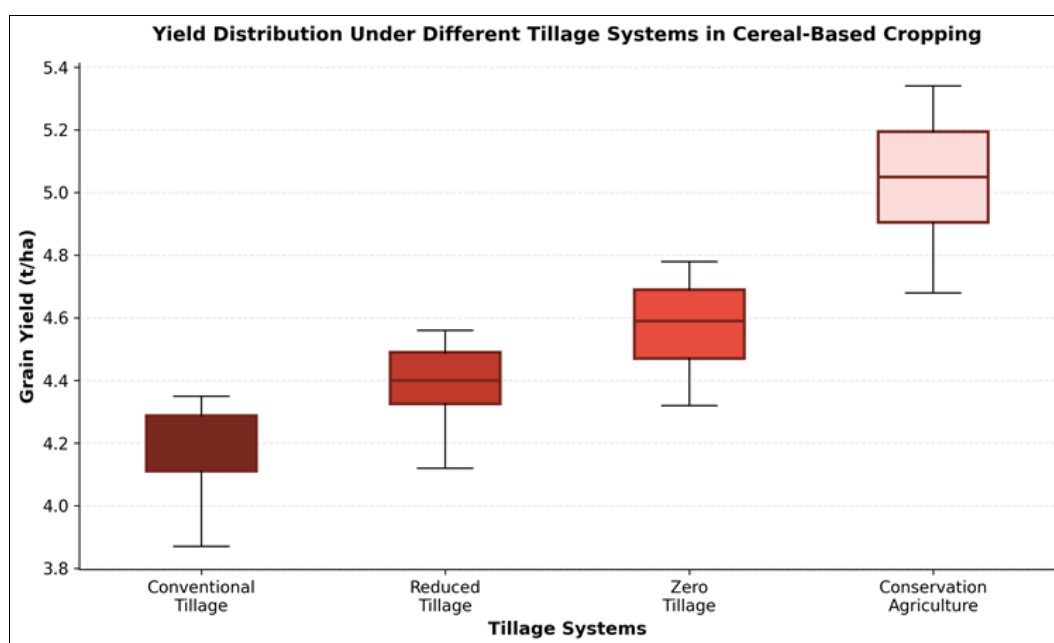


Fig 2: Distribution of grain yield under different tillage systems showing yield stability

Similar carbon gains under conservation agriculture have been reported by previous researchers across diverse agro-ecological conditions [4]. The depth-wise distribution of carbon, with higher concentrations in surface layers, reflects the stratification pattern characteristic of no-till systems [6].

The yield improvement under conservation agriculture can be attributed to multiple soil health benefits arising from enhanced organic carbon status. Improved water retention, better nutrient

cycling, and enhanced biological activity collectively contribute to favorable growing conditions [8]. The reduced yield variability under conservation agriculture, as evident from box plot analysis, indicates improved resilience to environmental stresses [10]. These findings corroborate earlier reports documenting productivity stabilization under conservation systems following initial transition periods [5].

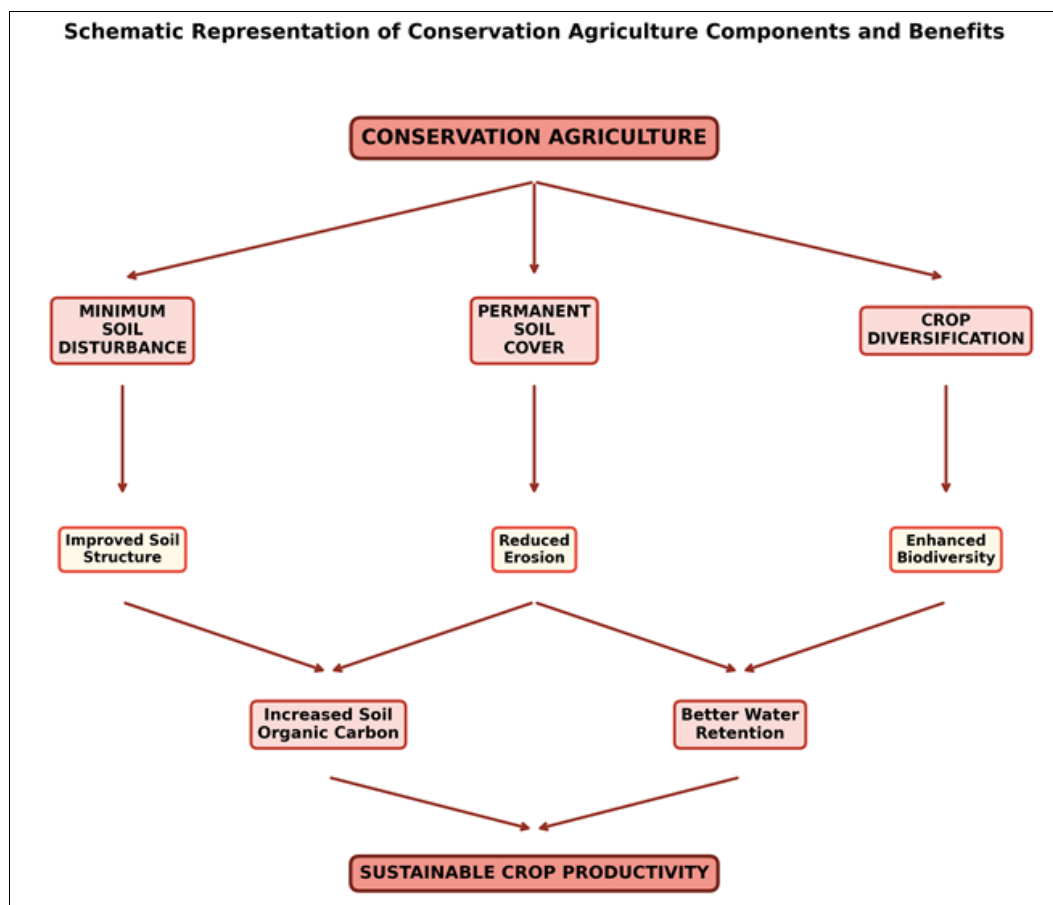


Fig 3: Schematic representation of conservation agriculture components and their benefits for sustainable crop production

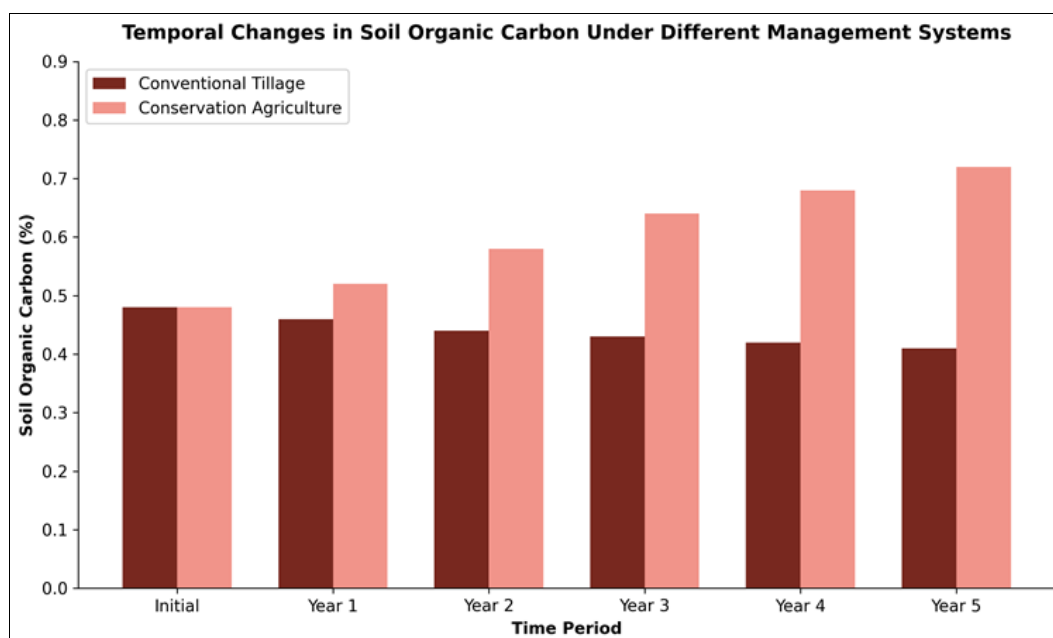


Fig 4: Temporal changes in soil organic carbon under conventional tillage and conservation agriculture over five years

Limitations: The research was conducted at a single location, limiting extrapolation to diverse soil types and climatic conditions. The transition phase challenges including weed pressure and initial yield depression that often accompany conservation agriculture adoption were not extensively evaluated. Economic analysis comparing input costs and returns across systems was not performed. The five-year duration, while adequate for detecting trends, may not capture full equilibrium carbon levels achievable under long-term conservation

management. Future multi-location research addressing these aspects would strengthen recommendations for wider adoption.

Conclusions: This research provides evidence that conservation agriculture significantly improves soil organic carbon status and crop productivity in cereal-based cropping systems. Implementation of conservation agriculture principles led to 50 percent higher soil organic carbon compared to conventional tillage, with carbon content increasing from 0.48 to 0.72 percent

over five years while declining to 0.41 percent under conventional practices. The carbon stock under conservation agriculture reached 30.6 tonnes per hectare, substantially exceeding other management systems.

Crop productivity responded positively to improved soil health, with grain yield reaching 5.18 tonnes per hectare under conservation agriculture compared to 4.22 tonnes under conventional tillage, representing a 22.7 percent yield advantage. The positive and significant relationship between soil organic carbon and crop yield validates that soil health investments translate into tangible productivity benefits. Reduced yield variability under conservation agriculture indicates enhanced production stability, which is increasingly important under climate uncertainty.

The three pillars of conservation agriculture comprising minimal soil disturbance, permanent soil cover, and crop diversification work synergistically to build soil organic carbon stocks and create favorable conditions for crop growth. These practices should be adopted as an integrated package rather than individual components for maximum benefits. The findings support promotion of conservation agriculture as a pathway for sustainable intensification of cereal production systems, addressing the dual challenges of maintaining productivity while preserving soil resources for future generations.

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