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Impact of Conservation Agriculture on Soil Health in Odisha

*Sulagna Mohanty, Dr. Anshuman Nayak and Dr. Ipsita Kar
College of Agriculture, OUAT, Bhubaneswar, Odisha, India
*Corresponding Author's email: sulagnamohanty35@gmail.com

Odisha's agricultural soils, predominantly acidic Inceptisols and laterites, face mounting degradation pressures from intensive tillage, nutrient depletion, and soil erosion. Conservation agriculture (CA) — minimum tillage, residue retention, and diversified cropping systems — offers a viable pathway to restore and sustain soil health across the state's diverse agro-ecological zones. This review synthesizes evidence from field studies conducted in upland, rainfed, and irrigated cropping systems of Odisha, examining CA's influence on key soil health indicators including organic carbon fractions, microbial biomass, aggregate stability, available nutrient pools, and erosion dynamics. Findings indicate that CA practices significantly improve soil organic matter, enhance biological activity, and mitigate erosion.

Keywords: Conservation agriculture, zero tillage, conservation agriculture production system (CAPS), soil organic carbon (SOC), soil microbial biomass

Introduction

Agriculture in Odisha is characterized by its highly diverse agroecological landscape — spanning coastal plains, river valleys, upland plateaus, and tribal hilly zones — with rice being the dominant crop grown predominantly under rainfed conditions. Despite the state's agricultural richness, soil degradation has emerged as a critical concern. A detailed assessment of soil health status across various districts in Odisha reveals significant challenges, including widespread soil acidity and deficiencies in essential nutrients such as organic carbon, phosphorus, potassium, sulfur, zinc, and boron. In this context, Conservation Agriculture (CA) has gained increasing attention as a sustainable land management strategy. CA is built on three core principles: minimum soil disturbance (reduced/zero tillage), permanent organic soil cover through crop residue retention, and crop diversification through rotations. (Chan *et al*., 2017; Pradhan *et al*., 2016) A shift towards more sustainable cropping systems such as conservation agriculture production systems (CAPS) may help in maintaining soil quality as well as improving crop production and farmer's net economic benefit. (Chan *et al*., 2017; Roul *et al*., 2015)

Soil Health Challenges in Odisha

Before examining the impact of CA, it is important to understand the baseline soil health situation in the state. Studies reveal significant challenges including widespread soil acidity and deficiencies in essential nutrients such as organic carbon, phosphorus, potassium, sulfur, zinc, and boron across various districts in Odisha, emphasizing the necessity for customized soil management practices. (Dixit *et al*., 2020). Practices like intensive tillage operations, absence of crop residue, imbalance use of chemical fertilizers, and lack of crop rotation in conventional farming lead to deterioration of soil.

Conservation Agriculture Research in Odisha

Tillage Management and Cropping Systems

Some of the most important CA research in Odisha has focused on upland and tribal areas. This research assessed the effects over three years (2011–2014) of reduced tillage, intercropping, and cover cropping practices customized for maize-based production systems in upland areas of Odisha, India. Results showed that maize grain yield did not differ significantly over time or among CAPS treatments, while cowpea yield was considered as an additional yield in intercropping systems. (Pradhan *et al.*, 2016; Roul *et al.*, 2015) Mustard and horsegram grown in plots after maize-cowpea intercropping recorded higher grain yields of 25 and 37%, respectively, as compared to those without intercropping. (Pradhan *et al.*, 2016). In eastern India in general and in Odisha in particular, reduced tillage in maize and zero-tillage direct seeded rice are preferred, as reported by many workers. (Pradhan *et al.*, 2016; Roul *et al.*, 2015)

Research in Rice-Based Systems at Bhubaneswar

A particularly significant experiment was conducted at Bhubaneswar, Odisha. An experiment conducted at Bhubaneswar, Odisha, India, in 2018–2019 and 2019–2020 comprised two rice cultivars ('Manaswini' and 'Hasanta') and three nitrogen management practices — 100% soil test-based nitrogen (STN), 75% STN + in situ green manuring (Sesbania), and 50% STN + green manuring — in the main plot. Sub-plots consisted of three tillage methods for succeeding toria–sweet corn: zero tillage (ZT), conventional tillage (CT), and a furrow-irrigated raised bed (FIRB) — to assess system nutrient uptake, productivity, and soil quality.

Impact on Specific Soil Health Parameters

Soil Organic Carbon (SOC)

Soil organic carbon is the most critical indicator of soil health, and CA's impact on it in eastern India's cropping systems is well-documented. Zero tillage in combination with crop residue retention increased the organic carbon by 1.01 to 1.18-fold as compared to conventional till plots, with residue retention with zero-till showing an increase of 18.46% in OC in the upper layer of soil (0–10 cm) and an increase of 15% in 10–20 cm compared to conventional tillage practice. (Nandan *et al.*, 2019). The ZT system enhanced the total organic carbon and its fractions by 16.8% and 9.8% over conventional tillage at 0–5 and 5–10 cm respectively. (Nandan *et al.*, 2019) Zero-tillage under rice-maize systems increases the soil sequestration of carbon due to higher biomass addition. (Nandan *et al.*, 2019)

Soil Physical Properties: Aggregation and Structure

Zero-till crop establishment treatments increased the very-labile carbon fraction by 21%, and notably, higher passive carbon pools in conservation tillage practices suggest that conservation tillage could stabilize the recalcitrant form of carbon that persists longer in the soil. (Nandan *et al.*, 2019) Zero-till crop establishment treatments also had higher water-stable macro-aggregates, macro-aggregates: micro-aggregates ratio and aggregate carbon content over conventional tillage. (Nandan *et al.*, 2019) Macro-aggregates protect the SOC, but disruption via tillage exposes the micro-aggregate carbon pool to decomposers and thereby amplifies subsequent mineralization. (Nandan *et al.*, 2019).

Soil Nutrient Dynamics

The availability of nitrogen in 0–10 cm depth with complete zero-tillage practice was found to be the highest. (Mohanty & Mishra, 2014; Sarkar *et al.*, 2024) With the increase in soil depth, the content of available nutrients (N, P, and K) was low for all treatments. An accumulation of P and K with zero/reduced tillage with all three crop residues either retained or incorporated occurs in the upper soil layers, with zero tillage resulting in a 1.32-fold increase of P in 0–10 cm depth. (Mohanty & Mishra, 2014).

Soil Microbial Biomass and Biological Activity

Soil biological health is a sensitive indicator of management change. As the crop season progressed, standing stubble from the previous rice crop decomposed, resulting in higher microbial biomass carbon (MBC) in zero-tillage treatment than the conventional tillage.

MBC showed a 103% and 46.6% increase over the conventional tillage at the most vegetative phase of the cropping season. (Chaudhary & Sharma, 2019). CA practices create a more friendly and laminated environment for proliferation of soil microorganisms and other macro- and micro-fauna.

Soil Erosion and Water Conservation

In tribal areas of Odisha, farmers employ natural farming methods such as stone and wood log bunding to reduce soil erosion during monsoon seasons. Stone bunding with broom grass increased soil and water conservation efficiency by 33.9% and 58.9%, respectively. (Mishra *et al.*, 2013) Paddy cultivation in Jhola land reduces runoff and soil loss, boosting yields by 22%. (Mishra *et al.*, 2013). In zero-tillage, crop residues act as a barrier between soil and the open environment which may have a great role in soil erosion reduction and soil quality improvement.

Challenges to Adoption of CA in Odisha

Despite its demonstrated benefits, the adoption of conservation agriculture faces significant barriers:

- Because conservation agriculture may take a decade or longer to realize the full benefits, there is a need to identify shorter-term indicators in order to assess performance and techno-economic feasibility of CAPS before making long-term recommendations. (Idol *et al.*, 2017)
- Increasing resource degradation problems such as groundwater depletion, waterlogging, salinization, soil erosion, loss of biodiversity, and invasive species further add to food security challenges.
- Small and marginal farmers, who dominate Odisha's agricultural landscape, face financial constraints in accessing machinery for zero-tillage or residue management. (Mishra *et al.*, 2018)

Way Forward

The manuscript advocates for the implementation of regenerative agriculture practices like cover cropping, reduced tillage, and organic amendments to address soil health issues. Furthermore, it underscores the need for integrated nutrient management strategies combining organic and inorganic sources to replenish soil nutrients and enhance crop productivity. It calls for comprehensive training programs to educate farmers, extension workers, and agricultural professionals on the benefits and application of these practices.

Key priorities include:

- Scaling up zero-tillage direct-seeded rice in lowland systems
- Promoting crop residue retention through incentives and awareness
- Integrating cover crops and green manures (e.g., *Sesbania*) into rice-based rotations
- Expanding the Soil Intelligence System's digital soil mapping to all districts of Odisha

Conclusion

Conservation agriculture represents a transformative pathway for improving soil health in Odisha — a state where soil degradation, acidity, and nutrient depletion threaten long-term agricultural sustainability. The evidence from multiple research trials across Odisha and eastern India consistently demonstrates that reduced tillage, crop residue retention, and diversified cropping systems significantly improve soil organic carbon, nutrient availability, microbial activity, aggregate stability, and erosion resistance. While short-term adoption barriers remain, the long-term gains in soil health, productivity, and climate resilience make conservation agriculture an essential strategy for the state's agricultural future.

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