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Conservation agriculture induced changes in soil dehydrogenase activity under a rice- chickpea cropping system

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Abstract

Conservation agriculture (CA) is a sustainable soil management approach that improves soil biological functioning and ecosystem resilience. Soil dehydrogenase activity (DHA) is a sensitive indicator of microbial activity and soil biological health. The present study was conducted to assess the effect of different conservation agriculture practices on soil DHA in a rice–chickpea cropping system. Five tillage and residue management practices involving combinations of transplanted/direct-seeded rice, zero/conventional tillage and residue retention were evaluated. Soil DHA was determined at initial, flowering and harvest stages of both crops using the 2,3,5-triphenyl tetrazolium chloride (TTC) reduction method. Significant differences in DHA were observed among conservation agriculture treatments during both rice and chickpea phases. The highest DHA was consistently recorded under *zero-till direct-seeded rice followed by zero-till chickpea* with 20 cm standing stubble retention (T_3), whereas the lowest activity was observed under conventional tillage without residue retention. During the rice phase, T_3 recorded mean DHA values of 40.88, 57.26 and 49.45 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at the initial, flowering and harvest stages, respectively. Similarly, during the chickpea phase, T_3 recorded the highest DHA values of 40.15, 66.76 and 57.04 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at the respective growth stages. Dehydrogenase activity increased up to flowering and declined slightly at harvest, reflecting the influence of crop growth dynamics on microbial activity. The enhanced DHA under zero tillage with residue retention may be attributed to improved organic matter availability, reduced soil disturbance and favourable microbial habitats. The study highlights that conservation agriculture, particularly zero tillage combined with residue retention, improves soil biological activity and contributes to sustainable soil health management in the rice–chickpea cropping system.

Keywords: Conservation agriculture, dehydrogenase activity, soil microbial activity, zero tillage, crop residue retention, rice-chickpea cropping system, soil biological health

Introduction

Global agriculture is under increasing pressure to meet the food demands of a rapidly growing population while maintaining the productivity and sustainability of natural resources. However, achieving this goal has become increasingly challenging due to widespread soil degradation, declining soil fertility and the adverse impacts of climate change. Conventional agricultural practices, characterized by intensive tillage, continuous crop residue removal and excessive reliance on chemical fertilizers, have accelerated the deterioration of soil physical, chemical and biological properties, leading to reduced soil organic matter, impaired ecosystem functioning and declining long-term agricultural productivity (Lal, 2015; FAO, 2017) ^[7, 4]. These concerns have highlighted the urgent need for sustainable land management strategies that can enhance soil health while maintaining crop productivity. In this context, conservation agriculture (CA) has emerged as a promising and widely adopted production system based on three interrelated principles: minimum soil disturbance, permanent soil cover through crop residue retention and diversified crop rotations (Hobbs *et al.*, 2008; Kassam *et al.*, 2019) ^[5, 6]. By improving soil quality, enhancing resource use efficiency and increasing the resilience of agroecosystems to climatic variability, conservation agriculture is increasingly recognized as a key approach for

achieving sustainable agricultural production.

Soil biological properties are among the most sensitive indicators of changes in soil management and play a crucial role in maintaining soil fertility and ecosystem functioning. Soil microorganisms regulate organic matter decomposition, nutrient mineralization and the transformation of essential nutrients, thereby sustaining plant growth and productivity. Because microbial communities respond rapidly to changes in management practices, biological indicators are increasingly used to assess soil quality and the effectiveness of sustainable agricultural practices. Among these indicators, soil enzyme activities provide valuable information on microbial functioning and nutrient cycling, making them reliable measures of soil biological health (Dick, 1994; Burns *et al.*, 2013) [3, 1].

Among the various soil enzymes, dehydrogenase is considered one of the most important indicators of microbial activity because it is an intracellular enzyme found exclusively in viable microbial cells. Dehydrogenase activity (DHA) is closely associated with microbial respiration and reflects the overall metabolic activity of soil microorganisms (Casida *et al.*, 1964) [2]. Since the enzyme is active only in living cells, its activity is highly responsive to changes in soil management, organic matter availability and environmental conditions. Consequently, DHA has been widely used as a sensitive indicator for evaluating soil biological quality, microbial abundance and nutrient cycling under different agricultural production systems (Nannipieri *et al.*, 2012) [8].

Conservation agriculture creates favourable conditions for soil microbial growth by reducing soil disturbance, maintaining residue cover and improving soil organic carbon levels. Crop residue retention provides a continuous source of carbon and energy for soil microorganisms, while reduced tillage preserves soil aggregates and microbial habitats, resulting in enhanced microbial biomass and enzyme activities. Numerous studies have reported significantly higher dehydrogenase activity under conservation agriculture than under conventional tillage, indicating improved soil biological functioning and enhanced nutrient transformation (Six *et al.*, 2004; Palm *et al.*, 2014; Kassam *et al.*, 2019) [10, 9, 6]. Improved microbial activity under CA also contributes to better soil aggregation, increased water infiltration, efficient nutrient utilization and greater resilience of cropping systems to environmental stresses.

The rice–chickpea cropping system is one of the predominant cropping sequences in South Asia, particularly in the Indo-Gangetic plains and central India, contributing significantly to food security and farm income, particularly in central India, where it contributes substantially to food security and farm income. However, continuous conventional cultivation in this system has led to declining soil organic carbon, deterioration of soil biological properties and reduced nutrient-use efficiency. Adoption of conservation agriculture practices has the potential to reverse these adverse effects by improving soil physical, chemical and biological characteristics. However, limited information is available regarding the comparative effects of integrated tillage and residue management practices on soil enzymatic activity across different crop growth stages in rice–chickpea systems. Information regarding its effects on soil biological indicators, particularly dehydrogenase activity, under the rice–chickpea cropping system remains relatively limited under Indian agro-ecological conditions.

Therefore, the present investigation was undertaken to evaluate the effect of conservation agriculture practices on soil dehydrogenase activity in a rice–chickpea cropping system. The study aims to generate scientific evidence on the response of soil microbial activity to conservation agriculture and to provide

insights into its potential role in improving soil biological health and ensuring the long-term sustainability of rice–chickpea production systems.

Materials and Methods

Soil Dehydrogenase Activity

The field experiment was conducted during the *kharif* and *rabi* season of 2024-25 and 2025-26 at the Instructional cum Research Farm of Indira Gandhi Krishi Vishwavidyalaya in Raipur, Chhattisgarh. The experiment was laid out in Randomized Block Design which consisting of 5 treatments and 4 replications that are, T₁ - Transplanted rice - conventional tilled chickpea (without residues), T₂ - Transplanted rice - zero tilled chickpea (with standing stubbles of rice), T₃ - Zero tilled direct seeded rice - zero tilled chickpea (with standing stubbles of rice), T₄ - Conventional tilled direct seeded rice - Conventional tilled chickpea (without residues) and T₅ - Conventional tilled direct seeded rice - zero tilled chickpea (with standing stubbles of rice). For soil dehydrogenase activity sampling of soil was done before sowing, at flowering and after harvest in both the crops i.e. rice and chickpea.

Soil dehydrogenase activity (DHA) was determined using the 2,3,5-triphenyl tetrazolium chloride (TTC) reduction assay following the method of Casida *et al.* (1964) [2], with slight modifications. Briefly, 3 g of field moist soil was placed in a sterile screw cap test tube and amended with 0.1 g of calcium carbonate (CaCO₃), 0.2 mL of 3% (w/v) TTC solution and 0.5 mL of 1% (w/v) glucose solution. The contents were thoroughly mixed to ensure uniform distribution of the reagents before incubation.

The tubes were incubated at 37 ± 1°C for 24 h under dark conditions to facilitate the microbial reduction of TTC to triphenyl formazan (TPF), a stable red coloured compound indicative of microbial oxidative activity. Following incubation, 10 mL of methanol was added to each tube to extract the produced TPF, and the samples were shaken for 6 h on a rotary shaker. The resulting suspension was filtered through Whatman No. 1 filter paper, and the filtrate was quantitatively transferred to a 100 mL volumetric flask. The final volume was adjusted to 100 mL with methanol.

The absorbance of the methanolic extract was measured at 485 nm using a UV visible spectrophotometer. Soil dehydrogenase activity was quantified from a standard calibration curve prepared using analytical grade triphenyl formazan (TPF) and expressed as µg TPF g⁻¹ dry soil h⁻¹. The results were expressed on a dry soil basis after determining soil moisture content. Dehydrogenase activity was used as an indicator of the overall oxidative activity of the soil microbial community and consequently, of soil biological health under different conservation agriculture practices.

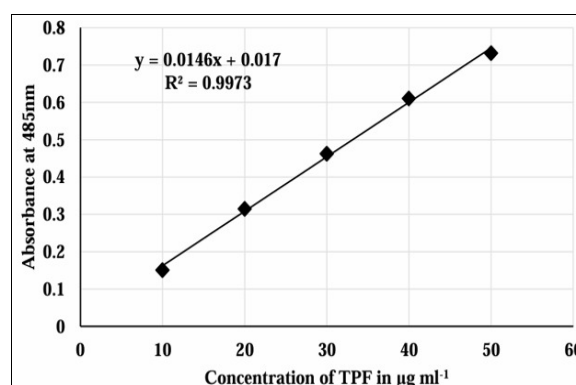


Fig 1: Standard curve for estimation of dehydrogenase activity in soil



A: Airtight screw cap test tube B: TTC C: Adding of TTC to the sample D: Mixing of sample with TTC E: Incubation F: Adding ethanol after incubation G: Filtration of sample H: Reading on spectrophotometer

Results

Soil Dehydrogenase Activity

Soil dehydrogenase activity (DHA) was significantly influenced by conservation agriculture practices during both phases of the rice-chickpea cropping system. The response of DHA varied with crop growth stages, with maximum activity generally recorded at flowering followed by a slight decline at harvest. The treatment-wise variation in DHA during the rice phase is presented in Table 1, while the corresponding changes during the chickpea phase are presented in Table 2.

Rice

During the rice season, conservation agriculture practices significantly affected soil dehydrogenase activity at all crop growth stages (Table 1). Among the evaluated treatments, T₃ consistently recorded the highest DHA throughout the crop growth period. The mean DHA under T₃ was 40.88 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at the initial stage, which increased to 57.26 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at flowering and declined to 49.45 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at harvest.

The second highest DHA was recorded under T₅ (conventional-till direct-seeded rice followed by zero-till chickpea with 20 cm standing stubble), with corresponding mean values of 36.64, 50.11 and 39.68 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at the initial, flowering and harvest stages, respectively. Treatment T₄ (conventional-till direct-seeded rice followed by conventional-till chickpea without residue) showed intermediate values of 35.08, 48.99 and 38.63 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at the respective growth stages.

The lowest dehydrogenase activity during the rice phase was recorded under T₂ (transplanted rice followed by zero-till chickpea with 20 cm standing stubble), with mean values of 27.79, 37.81 and 32.30 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at the initial, flowering and harvest stages, respectively. Statistical analysis revealed significant differences among treatments at all crop growth stages (Table 1).

Chickpea

A similar trend was observed during the chickpea phase of the cropping system (Table 2). Treatment T₃ (zero-till direct-seeded rice followed by zero-till chickpea with 20 cm standing stubble) recorded the highest DHA at all growth stages, with mean values of 40.15 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at the initial stage, 66.76 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at flowering and 57.04 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at harvest.

Treatment T₅ ranked second, recording DHA values of 37.46, 62.79 and 53.19 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} at the initial, flowering and harvest stages, respectively. This was followed by T₄, which recorded values of 29.84, 51.09 and 44.56 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} , respectively. The lowest DHA during the chickpea phase was observed under T₁ (transplanted rice followed by conventional-till chickpea without residue), with corresponding mean values of 27.20, 46.11 and 39.83 $\mu\text{g TPF g}^{-1}$ dry soil h^{-1} . The differences among treatments were statistically significant at the 5% level of probability (Table 2).

Table 1: Dehydrogenase activity (DHA) at different periods of crop growth as influenced by conservation agriculture practices in rice under rice-chickpea cropping system

Treatment		At initial			At flowering			At harvest		
		2024	2025	Mean	2024	2025	Mean	2024	2025	Mean
T ₁	Transplanted rice - conservational tilled chickpea (without residue)	28.30	29.40	28.85	36.58	37.90	37.24	31.18	31.55	31.36
T ₂	Transplanted rice - zero tilled chickpea (20 cm standing stubble in chickpea)	27.05	28.53	27.79	37.58	38.05	37.81	32.15	32.45	32.30
T ₃	ZT direct seeded rice - zero tilled chickpea (20 cm standing stubble in chickpea)	39.40	42.35	40.88	56.20	58.33	57.26	48.65	50.25	49.45
T ₄	Conventional tilled direct seeded rice - conventional tilled chickpea (without residue)	34.13	36.03	35.08	48.55	49.43	48.99	38.25	39.00	38.63
T ₅	Conventional tilled direct seeded rice - zero tilled chickpea (20 cm standing stubble in chickpea)	35.43	37.85	36.64	49.83	50.40	50.11	39.15	40.20	39.68
SEm $\pm$		1.70	2.25	1.66	1.83	2.11	1.62	1.79	1.98	1.39
CD (P=0.05)		5.23	6.93	5.11	5.65	6.51	5.00	5.52	6.09	4.28

Table 2: Dehydrogenase activity (DHA) at different periods of crop growth as influenced by conservation agriculture practices in chickpea under rice-chickpea cropping system

Treatment	At initial			At flowering			At harvest		
	2024	2025	Mean	2024	2025	Mean	2024	2025	Mean
T ₁ Transplanted rice - conservation tilled chickpea (without residue)	26.65	27.75	27.20	45.15	47.08	46.11	38.20	41.45	39.83
T ₂ Transplanted rice - zero tilled chickpea (20 cm standing stubble in chickpea)	30.00	31.88	30.94	56.75	59.35	58.05	48.50	50.95	49.73
T ₃ ZT direct seeded rice - zero tilled chickpea (20 cm standing stubble in chickpea)	38.90	41.40	40.15	64.65	68.88	66.76	55.65	58.43	57.04
T ₄ Conventional tilled direct seeded rice - conventional tilled chickpea (without residue)	29.33	30.35	29.84	50.25	51.93	51.09	43.25	45.88	44.56
T ₅ Conventional tilled direct seeded rice - zero tilled chickpea (20 cm standing stubble in chickpea)	36.25	38.68	37.46	61.38	64.20	62.79	52.30	54.08	53.19
SEm±	1.18	1.48	1.32	1.78	1.91	1.83	1.23	1.36	1.26
CD (P=0.05)	3.64	4.55	4.06	5.47	5.88	5.64	3.80	4.19	3.88

Discussion

Soil dehydrogenase activity (DHA) is considered a sensitive biochemical indicator of soil microbial activity because it represents the oxidative activity of viable microorganisms and reflects the overall biological functioning of soil ecosystems (Casida *et al.*, 1964) ^[2]. In the present study, conservation agriculture practices significantly enhanced soil DHA in both rice and chickpea phases of the rice-chickpea cropping system. The higher DHA observed under conservation agriculture treatments, particularly T₃ (zero-till direct-seeded rice followed by zero-till chickpea with 20 cm standing stubble) and T₅ (conventional-till direct-seeded rice followed by zero-till chickpea with 20 cm standing stubble), indicates improved microbial activity and favourable soil biological conditions compared with conventional tillage-based systems.

The greater dehydrogenase activity under T₃ can be attributed to the combined effects of zero tillage and crop residue retention, which minimize soil disturbance and provide a continuous supply of organic substrates for microbial growth. Residue retention enhances soil organic carbon availability, improves moisture conservation and creates a favourable microhabitat for soil microorganisms, thereby stimulating microbial respiration and enzyme production. Similar findings have been reported by Six *et al.* (2004) ^[10], who demonstrated that reduced soil disturbance and increased organic matter inputs under conservation agriculture improve microbial biomass and enzyme activities through enhanced carbon stabilization and improved soil aggregation.

The positive influence of standing stubble on DHA was evident from the higher activity recorded in residue-retained treatments compared with treatments without residue. Crop residues act as an important energy source for heterotrophic microorganisms by supplying carbon compounds required for microbial metabolism. Their decomposition promotes microbial proliferation and enhances microbial metabolic activity and associated enzyme production involved in nutrient cycling. Burns *et al.* (2013) ^[1] emphasized that soil enzyme activities are closely linked with organic matter availability and microbial processes, making them reliable indicators of changes in soil management practices.

The higher DHA under zero-till systems may also be associated with reduced physical disturbance of soil aggregates. Intensive tillage disrupts soil structure, accelerates organic matter decomposition and exposes protected carbon pools to rapid mineralization, which may negatively affect microbial habitats. In contrast, conservation agriculture maintains stable soil aggregates, protects microbial niches and enhances biological activity. Similar improvements in soil enzyme activities under reduced tillage and residue management have been reported by Palm *et al.* (2014) ^[9] and Kassam *et al.* (2019) ^[6].

The observed increase in DHA from the initial stage to

flowering in both crops can be explained by increased root growth, rhizosphere development and greater availability of root-derived carbon compounds during active crop growth. Root exudates containing sugars, amino acids and organic acids stimulate microbial multiplication and metabolic activity, resulting in enhanced dehydrogenase activity. The decline in DHA at harvest may be associated with reduced root activity, decreased carbon inputs from living roots and gradual stabilization of microbial activity after crop maturity. However, the higher harvest-stage DHA compared with the initial values indicates the beneficial residual effect of conservation agriculture practices on soil microbial functioning.

The chickpea phase recorded comparatively higher DHA values than the rice phase, particularly during flowering. This improvement may be attributed to the inclusion of a legume crop, which contributes additional organic inputs through root biomass, rhizodeposition and biological nitrogen fixation. Legume-based cropping systems enhance microbial diversity and nutrient cycling by increasing carbon and nitrogen availability in the rhizosphere. The enhanced microbial activity during chickpea cultivation under residue-retained treatments suggests that conservation agriculture provides cumulative benefits across cropping cycles.

The superiority of T₃ over other treatments highlights the importance of integrating zero-till direct-seeded rice with zero-till chickpea and residue retention as an effective strategy for improving soil biological health. The results demonstrate that conservation agriculture not only supports crop production but also promotes microbial-mediated soil processes essential for long-term soil fertility and sustainability. These findings are in agreement with earlier studies reporting increased microbial biomass, enzyme activity and improved soil quality under conservation agriculture systems (Dick, 1994; Nannipieri *et al.*, 2012) ^[3,8].

Overall, the present study confirms that conservation agriculture practices, particularly reduced soil disturbance combined with crop residue retention, enhance soil dehydrogenase activity and improve biological functioning in the rice-chickpea cropping system. The increased DHA under these practices indicates improved microbial activity and highlights their potential role in maintaining soil health and sustaining productivity in intensive cropping systems.

Conclusion

The present study highlights the positive influence of conservation agriculture practices on soil biological functioning in a rice-chickpea cropping system. Soil dehydrogenase activity was significantly enhanced under practices involving zero tillage and crop residue retention, with zero-till direct-seeded rice followed by zero-till chickpea with 20 cm standing stubble (T₃) consistently recording the highest microbial activity throughout

the crop growth period. The improved DHA under conservation agriculture indicates enhanced microbial respiration, efficient organic matter turnover and better soil biological health compared with conventional tillage systems. The increase in enzyme activity up to flowering followed by a slight decline at harvest reflects the relationship between microbial activity and crop growth dynamics. Overall, the integration of zero tillage and residue management represents an effective strategy for improving soil quality, maintaining microbial activity and promoting sustainable productivity of the rice-chickpea cropping system. Thus, conservation agriculture practices involving zero tillage and residue retention can serve as effective strategies for improving soil biological quality and sustaining productivity in rice–chickpea-based production systems.

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