



Effect of Conservation Agriculture-based Crop Establishment Options on Rice Growth in Rice-wheat System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Rice accounts for over 40% of India's total crop production, thereby reinforces the country's food security. However, rice production in India faces several challenges like high consumption of water, labour, and energy, which are becoming scarcer and more costly. Keeping above facts in view, an experiment was conducted during *Kharif* season of 2021 and 2022 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi to evaluate the effect of different conservation agriculture-based crop establishment options on growth of rice under rice-wheat system. The field experiment was arranged in a completely randomized block design having four replications and six different crop establishment methods, namely CE₁: Conventional till

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puddled transplanted rice - Conventional till wheat (no residue retention/incorporation), CE₂: Conventional till puddled transplanted rice - Conventional till wheat - Conventional till mung bean (Rice & Wheat residue removal, full mungbean residue incorporation), CE₃: Conventional till direct seeded rice - Zero till wheat (anchored residue retention of Rice), CE₄: Conventional till direct seeded rice - Zero till wheat - Zero till mung bean (anchored residue retention of Rice and full Mungbean residue incorporation), CE₅: Zero till direct seeded rice – Zero till wheat (anchored residue retention of Rice and Wheat), and CE₆: Zero till direct seeded rice – Zero till wheat – Zero till mung bean (anchored residue retention of Rice and Wheat and full mungbean residue retention). The CE₆ treatment (ZTR–ZTW–ZTMB) demonstrated significant superiority over the conventional CE₁ (CTR–CTW) method across all assessed growth parameters. Specifically, CE₆ resulted in an increase of up to 26% in plant height, 33% in number of tillers per m², and nearly 16% in the leaf area index during the early growth stage of rice.

Keywords: Rice; wheat; crop; kharif season; mungbean

1. INTRODUCTION

The rice-wheat cropping system (RWCS) is a pivotal component of Indian agriculture, particularly within the Indo-Gangetic Plains. This system plays an indispensable role in ensuring national food security and is instrumental in achieving self-sufficiency in staple grain production (Dhanda et al., 2022; Islam et al., 2022). However, the sustainability of this system is jeopardized by various environmental and agronomic challenges. The continuous implementation of the RWCS, especially in north-western India, has led to the soil nutrient depletion, groundwater scarcity, and rising production costs (Bera et al., 2017). These issues highlight the urgent need for sustainable practices (Dhanda et al., 2022; Kaur et al., 2021). At the same time, management of rice residues is also a major concern, which are frequently disposed through open burning. This practice contributes to air pollution and degrades soil health by causing nutrient loss (Leharwan et al., 2023). Sustainable residue management techniques, such as retaining and incorporating residues into the soil, have demonstrated the potential for enhancing soil properties and minimizing environmental impacts (Chandra et al., 2023; Singh & Sidhu, 2014). The persistent challenges and innovative practices within the rice-wheat cropping system underscore the need for advanced agricultural strategies. These strategies aim to sustain productivity while addressing environmental and resource-related issues, thereby ensuring the continued success and effectiveness of this vital agronomic practice in India (Dhanda et al., 2022; Jat et al., 2019).

Rice cultivation constitutes a fundamental aspect of India's agricultural sector and economy, serving as the primary food source for a

substantial portion of the population and playing a pivotal role in ensuring food security. For millions of farmers, rice farming represents a principal means of livelihood (Midya et al., 2021). This indispensable crop forms the backbone of the nation's food security system, appropriately encapsulated by the proverb "rice is life" within the Indian context (Mahajan et al., 2017). This is critical because rice accounts for over 40% of India's total crop production, thereby reinforcing the country's food security (Gandhi et al. 2016). However, rice production in India faces several challenges. Traditional practices, such as puddled transplanting, are becoming increasingly untenable because of their high consumption of water, labour, and energy, which are becoming scarcer and more costly. This unsustainable method necessitates a transition towards alternatives, such as direct-seeded rice (DSR) (Chauhan and Singh, 2016). Furthermore, climate change poses a significant threat to rice yields, exacerbating the difficulties farmers encounter owing to unpredictable weather patterns and their impact on livelihoods (Gandhi et al., 2016). The sustainability and future productivity of rice hinge on the adoption of innovative farming techniques. Rice farming remains a crucial component of India's agricultural landscape, necessitating ongoing adaptation to evolving environmental conditions and efficient resource management to sustain its essential role in food security and rural livelihood. There is an increasing emphasis on conservation agriculture as a solution to the challenges faced by the RWCS. Techniques, such as zero or minimal tillage and improved crop residue management, are recommended to enhance yield, efficiency, and sustainability. Additionally, incorporating legumes into the cropping sequence improves productivity and economic returns (Banjara et al., 2021). Practices such as

zero tillage contribute to the enhancement of soil health by increasing soil organic carbon content and mitigating soil compaction. Such conservation practices are pivotal for addressing the environmental challenges inherent in traditional rice cultivation, there by fostering a more sustainable and resilient agricultural system (Kumar et al., 2021; Chang et al., 2024; Tran et al., 2024; Pervaiz et al., 2024). Therefore, CA based options are needed under changing climatic and socio-economic conditions.

2. MATERIALS AND METHODS

The study was conducted during *Kharif* season of 2021 and 2022 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. The experimental sites remained consistent throughout the study period. The soil of the experimental field was characterized as sandy clay loam in texture, well-drained, and moderately fertile, with low levels of available nitrogen and phosphorus, and medium levels of available potassium. The field experiments were arranged in a completely randomized block design with four replications and six different crop establishment methods. The crop establishment methods were as follows: CE₁: Conventional till puddled transplanted rice - Conventional till wheat [CTPTR-CTW (no residue retention/incorporation)], CE₂: Conventional till puddled transplanted rice - Conventional till wheat - Conventional till mung bean [CTPTR - CTW - CTMB (full MB residue incorporation)], CE₃: Conventional till direct seeded rice - Zero till wheat [CT DSR - ZT W (anchored residue retention of R)], CE₄: Conventional till direct seeded rice - Zero till wheat - Zero till mung bean [CT DSR - ZTW - ZTMB (anchored residue retention of R and full MB residue incorporation)], CE₅: Zero till direct seeded rice - Zero till wheat [ZT DSR - ZT W (anchored residue retention of R and W)], and CE₆: Zero till direct seeded rice - Zero till wheat - Zero till mung bean [ZTDSR - ZTW - ZTMB (anchored residue of R and W and full MB residue retention)]. Field preparation was conducted as per the tillage requirements. The rice variety "Sarjoo 52" was sown/transplanted in all treatments, with a row spacing of 20 cm. In the transplanted rice treatments (CE₁ and CE₂), the field was tilled dry and wet, followed by puddling, and then 27-day-old seedlings were transplanted. For the conventional transplanted system, i.e. CE₁ and CE₂, the seeds were sown in nursery on the same day as the seeding for the

DSR crop establishment systems (CE₃, CE₄, CE₅, and CE₆) for ensuring the same physiological age of the rice plants under different treatments. The crop was sown at a seed rate of 30 kg ha⁻¹. In the CT DSR treatments (CE₃ and CE₄), the field was ploughed twice with a tractor-drawn cultivator, followed by planking. In the zero till DSR treatments (CE₅ and CE₆), sowing was done without soil disturbance, using a tractor-drawn zero-till seed cum fertilizer drill after the need-based application of Glyphosate (1 kg ha⁻¹) for controlling weeds. Pre-sowing irrigation was applied before sowing and subsequent irrigation was done as per crop demand.

3. RESULTS

3.1 Plant Height

Table 1 illustrates that the height of rice plants was significantly affected by different crop establishment (CE) methods at all growth stages observed (30, 60, 90 DAS, and at harvest) during both the year of investigation. There was a noticeable increase in plant height as the crop establishment method shifted from conventional puddled transplanted to conservation agriculture (CA). At 30 DAS, the shortest rice plants were recorded under CE₁: CTPTR-CTW, with heights of 24.8 cm in 2021 and 26.8 cm in 2022. Conversely, the tallest plants were found under CE₆: ZTDSR-ZTW-ZTMB (with residue retention in all crops), measuring 33.8 cm in 2021 and 35.0 cm in 2022, which were significantly taller than those under CE₁ and other treatments. Similar, pattern persisted at 60 DAS, where CE₆ again resulted in the tallest plants, with heights of 76.0 cm in 2021 and 80.1 cm in 2022, while CE₁ remained the shortest (67.5 cm and 71.8 cm, respectively). At 90 DAS, CE₆ continued to produce the tallest plants (105.7 cm in 2021 and 108.6 cm in 2022), followed by CE₅: ZTDSR-ZTW and CE₄: CTDSR-ZTW-ZTMB. The conventional puddled transplanted system (CE₁) had the shortest plants (96.2 cm and 96.1 cm) during both years. By harvest time, CE₆ consistently had the tallest plants (104.0 cm and 106.8 cm), while CE₁ recorded the shortest (94.6 cm and 94.5 cm). Overall, plant height increased progressively with the adoption of conservation agricultural practices, particularly those incorporating zero tillage and crop diversification (mungbean). These findings suggest that CA-based methods create a more conducive environment for crop growth throughout the crop

cycle, resulting in significantly taller plants compared with conventional systems.

3.2 Number of Tillers

The different crop establishment methods had a notable impact on the number of tillers per square meter at all growth stages (30, 60, and 90 DAS) over the two years (2021 and 2022) (Table 2). A steady rise in tiller numbers has been observed under conservation agriculture (CA)-based crop establishment approach, especially those incorporating zero tillage and crop diversification. At 30 DAS, the lowest tillers were found in CE₁: CTPTR–CTW, 107.50 m⁻² in 2021 and 109.25 m⁻² in 2022. However, a significant boost was noted with CA-based methods, with CE₆: ZTDSR–ZTW–ZTMB achieving the highest tiller count, at 159.25 m⁻² in 2021 and 164.00 m⁻² in 2022. At 60 DAS, tiller production increased in all the treatments. However, CE₆ again recorded the maximum tillers (391.00 m⁻² in 2021 and 394.00 m⁻² in 2022), followed by CE₅: ZTDSR–ZTW and CE₄: CTDSR–ZTW–ZTMB. In contrast, CE₁ consistently had the lowest numbers, with 344.75 and 350.25 tillers m⁻², respectively. These differences were statistically significant, as indicated by the CD values. At 90 DAS, similar trend persisted, with CE₆ reaching the highest tiller density (468.25 m⁻² in 2021 and 471.75 m⁻² in 2022), significantly surpassing all other

treatments. The lowest tiller density remained in CE₁ (424.75 and 431.50 tillers m⁻²). The gradual increase in tiller numbers with CA-based methods, particularly in CE₆, can be attributed to improved soil aeration, better moisture retention, and enhanced microbial activity facilitated by zero tillage and mungbean inclusion. These practices likely contributed to better root development and nutrient availability, thereby fostering robust tiller production.

3.3 Leaf Area Index (LAI)

Leaf Area Index (LAI), a crucial physiological factor affecting the photosynthetic efficiency of rice, was notably influenced by various crop establishment (CE) methods at all growth stages (30, 60, and 90 DAS) during both years of the study (2021 and 2022) (Table 3). At 30 DAS, LAI values ranged from 1.21 (2021) and 1.23 (2022) under CE₁: CTPTR–CTW to a significantly higher 1.45 (2021) and 1.47 (2022) in CE₆: ZTDSR–ZTW–ZTMB. This suggests that CA-based methods, promote early canopy development and leaf expansion. At 60 DAS, LAI values increased across all treatments, with CE₆ maintaining the highest values (3.36 in 2021 and 3.38 in 2022), followed by CE₅ and CE₄. The conventional treatment CE₁ recorded the lowest LAI at this stage (3.13 and 3.21), indicating a slower canopy development rate under traditional

Table 1. Effect of CA based crop establishment methods on plant height (cm) at different growth stages of rice

Crop Establishment methods	30 DAS		60 DAS		90 DAS		At harvest	
	2021	2022	2021	2022	2021	2022	2021	2022
CE ₁ : CTPTR-CTW	24.8	26.8	67.5	71.8	96.2	96.1	94.6	94.5
CE ₂ :CTPTR-CTW-CTMB	27.0	27.5	69.8	74.0	98.1	98.8	97.0	96.5
CE ₃ : CTDSR - ZT W	28.5	29.5	71.0	73.8	98.8	101.3	97.7	99.1
CE ₄ :CTDSR-ZTW-ZTMB	32.5	33.5	74.5	76.3	103.0	103.0	101.1	100.9
CE ₅ : ZT DSR-ZT W	32.0	33.0	73.8	78.3	102.8	105.5	100.5	102.6
CE ₆ :ZTDSR-ZTW-ZTMB	33.8	35.0	76.0	80.1	105.7	108.6	104.0	106.8
S.Em.±	1.57	1.86	1.87	1.64	2.03	2.60	1.77	2.06
CD (P=0.05)	4.74	5.62	5.65	4.95	6.13	7.82	5.33	6.21

Table 2. Effect of CA based crop establishment methods on number of tillers (m⁻²) at different growth stages of rice

Crop Establishment methods	30 DAS		60 DAS		90 DAS	
	2021	2022	2021	2022	2021	2022
CE ₁ : CTPTR-CTW	107.50	109.25	344.75	350.25	424.75	431.50
CE ₂ :CTPTR-CTW-CTMB	118.00	120.50	355.00	361.00	435.00	438.75
CE ₃ : CTDSR - ZT W	139.50	141.75	363.25	369.70	443.25	447.20
CE ₄ :CTDSR-ZTW-ZTMB	146.50	153.50	375.50	378.35	451.00	454.00
CE ₅ : ZT DSR-ZTW	151.00	157.25	381.25	383.75	455.00	460.25
CE ₆ :ZTDSR-ZTW-ZTMB	159.25	164.00	391.00	394.00	468.25	471.75
S.Em.±	4.56	5.76	5.51	5.35	6.34	6.40
CD (P=0.05)	13.75	17.35	16.61	16.13	19.12	19.29

Table 3. Effect of CA based crop establishment methods on Leaf Area Index (LAI) at different growth stages and grain yield of rice

Crop Establishment methods	30 DAS		60 DAS		90 DAS		Grain yield (kg ha ⁻¹)	
	2021	2022	2021	2022	2021	2022	2021	2022
CE ₁ : CTPTR-CTW	1.21	1.23	3.13	3.21	3.31	3.37	4027.50	4080.00
CE ₂ :CTPTR-CTW-CTMB	1.27	1.28	3.17	3.25	3.36	3.43	4115.58	4140.00
CE ₃ : CTDSR - ZT W	1.31	1.33	3.23	3.32	3.40	3.45	4207.50	4230.00
CE ₄ :CTDSR-ZTW-ZTMB	1.36	1.38	3.28	3.33	3.42	3.47	4252.50	4311.81
CE ₅ : ZT DSR-ZTW	1.39	1.43	3.33	3.35	3.44	3.51	4327.50	4402.50
CE ₆ :ZTDSR-ZTW-ZTMB	1.45	1.47	3.36	3.38	3.50	3.55	4396.09	4493.26
S.Em.±	0.03	0.03	0.03	0.03	0.04	0.04	54.10	63.84
CD (P=0.05)	0.08	0.08	0.08	0.10	0.11	0.11	163.06	192.44

puddled transplanting systems. At 90 DAS, the highest LAI was again observed under CE₆, with values of 3.50 in 2021 and 3.55 in 2022, significantly surpassing CE₁ (3.31 and 3.37). This indicates that CA-based practices supported better canopy growth, even during the reproductive stage, likely enhancing light interception, biomass accumulation, and photosynthates production.

3.4 Grain Yield

The grain yield of rice was significantly affected by different crop establishment methods during both the years of experimentation (2021 and 2022) (Table 3). There was a clear upward trend in grain yield as the practices shifted from conventional puddled transplanted system to conservation agriculture based crop establishment methods. In 2021, the lowest yield was recorded with CE₁: CTPTR–CTW, yielding 4027.50 kg ha⁻¹. Slightly higher yields were seen with CE₂: CTPTR–CTW- CTMB (4115.58 kg ha⁻¹) and CE₃: CTDSR–ZTW (4207.50 kg ha⁻¹). However, yields increased significantly with CA based practices. CE₄: CTDSR–ZTW–ZTMB and CE₅: ZTDSR–ZTW produced 4252.50 kg ha⁻¹ and 4327.50 kg ha⁻¹, respectively. The highest yield was achieved with CE₆: Zero till dry seeded rice followed by zero till wheat and zero till mungbean (ZTDSR–ZTW–ZTMB), which yielded 4396.09 kg ha⁻¹, outperforming most other treatments. A similar pattern in yield was observed in 2022, with yields ranging from 4080.00 kg ha⁻¹ in CE₁ to 4493.26 kg ha⁻¹ in CE₆. The yield improvement under CE₆ was statistically significant, as indicated by the critical difference (CD) values at P=0.05.

4. DISCUSSION

The implementation of zero till direct seeded rice (ZTDSR) followed by zero till wheat (ZTW) and zero till mung bean (ZTMB), with residue

retention, is linked to enhanced rice growth owing to several critical factors. Conservation agriculture (CA) practices, such as ZTDSR-ZTW-ZTMB, contributed to increase soil organic carbon (SOC) levels, which are instrumental in maintaining and improving soil quality, and promoting plant growth. (Dey et al., 2016; Sapkota et al., 2017; Mishra et al., 2024). The retention of crop residues augments nutrient availability in the soil. This approach enhances soil nitrogen pools, as residues from rice and mung beans exhibit a varied C:N ratio, thereby improving nitrogen utilization by crops. This increase in nutrient availability supports the overall growth and development of rice plants. (Dey et al., 2016; Thind et al., 2023). Practices such as ZTDSR with residue retention also enhance the soil physical properties, including soil structure and porosity. These enhancements improve root penetration and water retention capacity, creating a more favourable environment for plant growth and resulting in superior plant architecture (Kumar et al., 2019). Residue retention enhances microbial activity in soil, which is essential for nutrient cycling and soil health. By providing continuous organic matter input, microbial biomass increases, improving nutrient accessibility and promoting plant health (Sharma et al., 2019). Overall, ZTDSR-ZTW-ZTMB system with residue retention improved growth in rice by enhancing soil health through increased organic carbon, nutrient availability, and soil physical properties, along with improved water & nutrient use efficiency, and increased microbial activity. Collectively, these factors supported robust plant growth and development. Conservation agriculture (CA) techniques have led to increased rice yields owing to several important factors. First, CA incorporates methods such as minimal tillage, maintaining crop residues, and rotating crops, which gradually improve the soil structure and fertility. This results in a healthier soil, which is essential for maintaining higher

crop yields. For example, practices such as zero tillage and retaining crop residues in CA systems boost soil organic carbon levels and microbial health, fostering better root development and nutrient absorption, ultimately enhancing rice yields (Mishra et al., 2024; Song et al., 2024; Upadhyay et al., 2024). Furthermore, CA methods enhance water efficiency and productivity. Research indicates a notable decrease in water usage in CA systems compared with traditional methods, making rice farming more sustainable and adaptable to climate change (Jat et al., 2019). Improved water use efficiency leads to better crop performance and can significantly increase yield. Additionally, CA encourages crop rotations, such as incorporating legumes (e.g., mungbean) into rice-wheat systems, which can boost soil nitrogen levels and overall system productivity. This diversification not only increases yields, but also supports long-term soil health and economic gains (Jat et al., 2019). Finally, conservation agriculture lowers energy consumption and operational expenses by reducing the need for mechanical tillage and fuel usage. These efficiencies result in higher economic returns and can promote sustainable rice-farming practices (Nandan et al., 2020). Overall, conservation agriculture provides a holistic approach for sustainably increasing rice yields by enhancing soil health, optimizing water and nutrient utilization, and boosting the ecological resilience of rice-based cropping systems.

5. CONCLUSION

Based on the results presented here, it can be concluded that full conservation agriculture based crop establishment method, CE₆: ZTR–ZTW–ZTMB (with anchored residue retention in all the crops) has the potential to improve the rice growth and yield as compared to the conventional puddled transplanted method of rice within rice-wheat system of the eastern U.P.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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