Indian Journal of Agronomy **70** (2): 161–167 (June 2025)
DOI: 10.59797/ija.v70.i2.5598

Research Paper

Growth, productivity and profitability of wheat in pigeon pea–wheat rotation under contrasting production system

PRIYANKA SAHA[1], T.K. DAS[2], RAJ SINGH[3], RISHI RAJ[4], DIBAKAR MAHANTA[5], SUMAN SEN[6], ARKAPRAVA ROY[7], ALEKHYA GUNTURI[8], TARUN SHARMA[9], LALIT MAINWAY[10], RAHUL SADHUKHAN[11], SHASHANK PATEL[12], ANAMIKA BARMAN[13], SHITAL KUMAR[14] AND PLABANI ROY[15]

ICAR-Indian Agricultural Research Institute, New Delhi 100 012

Received: December 2024; Revised accepted: April 2025

ABSTRACT

A study conducted at ICAR-Indian Agricultural Research Institute, New Delhi during 2022–23 and 2023–24 to evaluated the impact of conventional agriculture (CT), conservation agriculture (CA), and organic agriculture (OA) on wheat under pigeon pea-wheat system. Conservation agriculture treatments such as zero till permanent narrow bed (CA-PNB), permanent broad bed (CA-PBB), and permanent flatbed (CA-PFB) with residue outperformed CT and OA on growth parameters such as plant height, dry matter accumulation, leaf area index and crop growth rate of wheat. The same treatment also showed higher yield attributing characteristics such as ear bearing tiller and number of grains per spike compared to other treatments. The CA based CA-PBB recorded the maximum grain yield of 5.37 and 5.58 t/ha in 2022–23 and 2023–24, respectively, representing ~20.1 and 18.7% increase over CT (4.47 t/ha & 4.70 t/ha). Among the production systems, CA treatments (CA-PNB, CA-PBB, CA-PFB) demonstrated a ~19.5% higher grain yield compared to the CT system. Similarly, for biological yield also, CA-PBB showed the highest biological yield (13.13 and 13.28 t/ha) with ~14.0 and 11.8% higher values over CT in 2022–23 and 2023–24, respectively. The CA treatments (CA-PNB, CA-PBB, CA-PFB) consistently outperformed others in economic parameters. The CA-PBB exhibited the highest net B: C in both years, with 2.03 in 2022–23 and 2.07 in 2023–24, showing ~50.4% and ~46.8% improvement over CT, respectively. In contrast, organic systems, particularly the CT-based OA-CT, demonstrated the highest cultivation costs (52.3×10^3 INR/ha in 2022–23 and 54.9×10^3 INR/ha in 2023–24) but did not show higher gross and net returns. Therefore, it may be concluded that conservation agriculture, particularly CA-PBB, which provides better growth, higher yields and income would be economically superior to conventional and organic agriculture.

Key words: Conservation agriculture, Conventional agriculture, Crop growth rate, Gross and net returns, Organic agriculture

The traditional rice-wheat cropping system (RWCS), widely practiced in the Indo-Gangetic Plains (IGP), is encountering significant sustainability issues, including weed proliferation, soil fertility depletion (Gathala *et al.,* 2013), micronutrient deficiencies (Dwivedi *et al.,* 2003), emergence of new pests and diseases, declining groundwater levels, increasing ecological footprints, and a decline in soil organic carbon (SOC), etc, collectively leading to the declining sustainability in production (Das *et al.,* 2016). Therefore, enhancing soil health and conserving resources have become key priorities, prompting scientists to devise innovative production systems and crop establishment techniques aimed at obtaining higher productivity (Das *et al.*, 2021). Hence, there is an urgent need to diversify and sustainably intensify the traditional RWCS, particularly focusing on the water- guzzling rice crop. Maize, cotton, and pigeon pea are suitable alternatives to rice during the *kharif* (rainy) season in the north-western IGP because of their relatively low water requirements. Moreover, including a legume crop into the cropping system may play a crucial role in improving soil health and ensuring the sustainability of production systems.

Based on a part of Ph.D. Thesis of the first author submitted to ICAR-Indian Agricultural Research Institute in 2024 (unpublished)

[1]**Corresponding author's Email:** tkdas64@gmail.com
[1]Subject Matter Specialist (Agronomy), Krishi Vigyan Kendra, West Garo Hills, ICAR-Research Complex for North Eastern Hill Region, Umiam, Meghalaya; [2,5]Principal Scientist, [3]Ex-Head, [4]Senior Scientist, [7,8,9,10,12,13,14,15]Ph.D. Research Scholar, Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi 110 012; [6]Senior Technical Officer, Indian Veterinary Research Institute, Izatnagar, Uttar Pradesh 243 112; [11]Assistant professor, MTTC&VTC, College of Horticulture, Thenzawl, CAU, Imphal, Manipur 796 186

Modern agriculture is an evolving approach that incorporates agricultural innovations and farming practices based on the use of high-yielding crop varieties, synthetic fertilizers, irrigation, agro-chemicals, etc. (Gamage *et al.,* 2022). These methods have exceeded the natural boundaries of the environmental limits and are unsustainable in the long term, causing numerous adverse effects on ecosystems and the environment. There is necessity of having alternative agriculture methods that operate harmoniously within the ecosystems while maintaining and increasing productivity. In the quest for sustainability, conservation agriculture (CA) and organic farming have emerged as promising and viable solutions. Organic farming and CA offer contrasting yet complementary pathways for sustainable farming by focusing on soil health, biodiversity conservation, and reduced reliance on external inputs. Yet, both approaches aim to address the limitations of conventional agriculture by focusing on soil health, biodiversity, and ecosystem conservation. The CA emphasizes on practices that maintain soil integrity and improve soil resilience, reduce greenhouse gas (GHG) emissions and promote soil carbon sequestration (Baghel *et al*., 2018; Raj *et al*., 2022). Organic farming, on the other hand, avoids the use of synthetic inputs, and relies on natural methods for nutrient management and pest control, thereby encouraging a more bio-diverse ecosystem. Despite offering numerous benefits, the adoption of CA has been low, particularly in India (3.5 million hectares). The initial yield declines following the adoption of CA, play a crucial role in lower adoption of CA (Corbeels *et al.,* 2014). This yield losses are more common when no tillage (NT) is adopted in isolation, without crop residue retention and crop diversification, particularly during the initial years of adoption (Jat *et al.,* 2014). Organic farming usually relies on intensive tillage inversion to eliminate weeds mechanically. Yet, organic production of field crops usually consumes up to 20% less energy than conventional non-organic agriculture (Williams *et al.,* 2017). However, environmental burdens, such as global warming potential (GWP) or eutrophication, can be greater under organic farming (Williams *et al.,* 2017). Thus, incorporating conservation tillage practices may improve both the environmental and economic performance of organic farming (Peigne, 2007). Reduced tillage and NT systems, along with crop residue addition, nitrogen fertilizer, farmyard manure incorporation, and integrated nutrient management, are expected to contribute to increased SOC accumulation and improved the sustainability of agricultural systems (Ghimire *et al.,* 2017). Incorporating conservation tillage systems into organic farming would be a new challenge for agroecosystem management. Moreover, analyzing pigeon pea-wheat rotation under these systems may offer valuable insights into how diversified approaches can address the issues of both productivity and sustainability. Integrating conventional agriculture, CA, and organic farming approaches could unearth optimal practices for optimizing productivity, minimizing environmental impacts, and enhancing soil health, ensuring long-term agricultural stability.

MATERIALS AND METHODS

The experiment was undertaken at the ICAR-Indian Agricultural Research Institute, New Delhi (28°35′ N; 77°12′ E; 228 m above the mean sea level) during 2022–23 and 2023–24. This region experiences a typical subtropical climate with an average annual precipitation of 670 mm. The soil is Mollisols, specifically identified as Typic Haplustept, featuring a clay loam texture. Eight treatments, each with three replications were laid out in a randomized block design. These encompassed four production system, i.e. conventional tillage (CT), conservation agriculture (CA) and conventional tillage based organic agriculture (OA-CT) and zero tillage based organic agriculture. The CA and OA systems comprised of different crops establishment methods such as zero till permanent narrow (PNB), broad (PBB) and flat (PFB) beds. Thus, the treatments were CT, CA-PNB, CA-PBB, CA-PFB, OA-CT, OA-PNB, OA-PBB and OA-PFB. The CT practice involved three tillage operations, including one with a disc plough and two with a cultivator, reaching up to a depth of 15 cm. In contrast, the CA approach completely avoided tillage operations. The PBBs had a width of 140 cm, with beds measuring 110 cm and furrows 30 cm wide. The PNBs consisted of 40 cm wide beds and 30 cm wide furrows, totaling 70 cm in width. Approximately 20% and 40% of the above-ground crop residues of pigeon pea and wheat was retained in all CA plots. Recommended rates of 150 kg N, 60 kg P_2O_5 and 40 kg K_2O/ha to wheat was given through chemical fertilizers such as urea, diammonium phosphate and muriate of potash in CT and CA treatments. However, for organic treatments N-equivalent amount of FYM was applied. The N equivalent amount of FYM led to application of ~14.55 and 13.94 t/ha of FYM in 2022–23 and 2023–24, respectively. The nutrient concentration of FYM was 0.83 and 0.86% N, 0.25 and 0.21% P and 0.51 and 0.53% K in 2022-23 and 2023–24, respectively. Glyphosate at 1.0 kg/ha was applied in the CA plots about one week before sowing. Pendimethalin (1.0 kg/ha) was applied 2 days after sowing (DAS) followed by, a tank-mix application of clodinafop-propargyl + metsulfuron-methyl (0.060 kg/ha + 0.005 kg/ha) was done in all the treatments at 30 DAS to control existing weeds for both of these treatments. However, for OA treatments, no such herbicides were used. Only manual weeding was done at 20 and 40 DAS for both crops. For above-ground dry matter estimation, 5 plants were randomly selected at 90 DAS and leaf area was measured using leaf area meter. These plant samples were dried under sun and further oven dried at 65±5°C for 48 h and weight was recorded. Crop growth rate was calculated as per standard process. Total number of ears bearing tiller, grains per spike and 1000 grains weight were computed and calculated from 5 randomly selected plants at harvest. Data were statistically analyzed using the analysis of variance (ANOVA) technique for randomized complete block design (Gomez and Gomez, 1984) and the significance of treatment means was tested by variance ratio (~F value) at 5% level of significance.

RESULTS AND DISCUSSION

Growth parameters

The conservation agriculture (CA) systems, particularly CA-PBB, demonstrated the highest plant height, leaf area index, dry matter accumulation, and crop growth rate in both years of study (Table 1). In 2022–23, CA-PBB recorded the maximum plant height of 107.7 cm, with ~3.3% increase over CT which had the plant height of 104.3 cm. The maximum leaf area index (5.89) was observed in CA-PFB, with ~21.2% higher value than CT (4.86). CA-PBB also showed the highest dry matter accumulation (1435.9 g/m²), which showed significantly higher values, marking a 41.9% increase over CT (1011.5 g/m²), and the highest crop growth rate (29.6 g/m²/day), which was ~48.0% higher than CT (20.0 g/m²/day). In 2023-24, CA-PBB again exhibited the highest plant height (108.8 cm), 2.3% higher than CT (106.4 cm), and the maximum leaf area index (5.95) was observed in CA-PFB, a 19.9% increase over CT (4.96). CA-PBB recorded the highest dry matter accumulation (1195.0 g/m²), showing a 20.5% increase over CT (991.3 g/m²), and the highest crop growth rate (29.3 g/m²/day), which was 26.3% higher than CT (23.2 g/m²/day). Among organic systems, OA-PBB treatment achieved the highest plant height, with 102.3 cm in 2022–23, whereas in 2023–24, OA-PFB with 102.0 cm plant height showed higher plant height. The highest leaf area index among organic treatments was observed in OA-CT (5.81 in 2023-24), comparable to CA-PBB Dry matter accumulation and crop growth rate in organic systems were consistently lower than CA treatments, with OA-PFB showing a marginal improvement over other organic treatment. Overall, conservation agriculture systems, particularly CA-PBB, emerged as the most effective production system across both years, demonstrating higher growth parameters compared to conventional and organic farming systems. The combination of zero tillage (ZT), varied crop rotation, and long-term crop residue retention in CA systems improves the physical, chemical, and biological qualities of the soil, which in turn gives crops the best growth environment (Bhattacharyya *et al.,* 2015; Das *et al.,* 2020). The CA techniques probably contributed to better soil nutrient levels, moderate soil temperature, and optimal soil moisture (Saad *et al.,* 2015) which resulted in better crop growth performance of wheat. The greenness of a plant indicates its potential for enhanced growth and productivity. Over the growth stages, greenness of wheat measured by green seeker was increased and the highest green seeker values were observed in CA based treatments, especially, in CA-PBB treatment (Figure 1). Higher green seeker values also correspond to higher grain yield (Figure 2). Leaf N concentration is positively correlated with yield and that leaf chlorophyll concentration is similarly correlated with leaf N concentration (Noulas *et al.,* 2018).

Table 1. Growth parameters of wheat at 90 DAS under different production system (pooled data of 2 years)

Treatment	Plant height (cm)		Leaf area index		Dry matter accumulation (g/m^2)		Crop growth rate ($g/m^2/day$)	
	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24
'CT'	104.3	106.4	4.86	4.96	1011.5	991.3	20.0	23.2
'CA-PNB'	107.3	108.4	4.46	4.28	1364.0	1159.4	29.2	29.3
'CA-PBB'	107.7	108.8	5.58	5.64	1435.9	1195.0	29.6	28.6
'CA-PFB'	106.7	107.8	5.89	5.95	1409.9	1164.4	28.6	27.3
'OA-CT'	99.7	95.7	5.75	5.81	925.2	933.6	18.6	18.0
'OA-PNB'	100.1	102.1	4.54	4.63	942.0	962.0	18.8	19.2
'OA-PBB'	102.3	99.2	4.78	4.64	966.8	976.5	18.9	18.0
'OA-PFB'	101.0	102.0	4.64	4.69	971.6	966.1	19.5	19.9
SEm±	1.8	1.8	0.09	0.09	15.1	17.8	0.79	0.4
CD (P=0.05)	5.5	5.5	0.27	0.26	45.8	54.1	2.4	1.2

CT, Conservation agriculture; CA-PNB, conservation agriculture permanent narrow bed; CA-PBB, conservation agriculture permanent broad bed; CA-PFB conservation agriculture permanent flatbed; OA-CT outperformed conservation agriculture; OA-PNB, Organic agriculture permanent narrow (PNB), broad; OA-PBB: Organic agriculture in permanent broad bed; OA-PFB: Organic agriculture in permanent flat bed

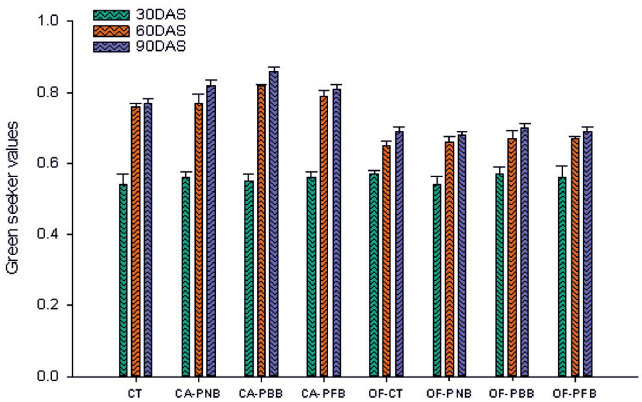

Fig. 1. Green seeker value of wheat across the growth stages under different production systems

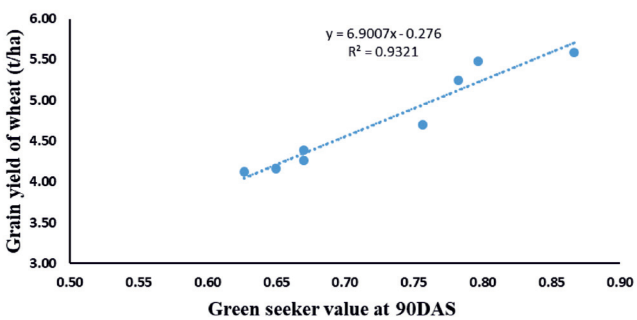

Fig. 2. Regression analysis of greenseeker value at 90DAS and grain yield of wheat

Yield attributing characteristics and Yield

The yield attributing characteristics such as ear-bearing tillers and number of grains per spike were varied significantly across treatments in both years of study (Table 2). In 2022–23, the CA treatment CA-PBB recorded the maximum number of ear-bearing tillers (547.5/m²), with ~28.1% higher values over CT plot, which had 427.5 tillers/m². Similarly, in 2023–24, CA-PBB again achieved the highest value of 567.5 tillers/m², reflecting ~34.1% increase compared to the CT plot (423.0 tillers/m²). Among the four production systems, CA treatments (CA-PNB, CA-PBB, and CA-PFB), demonstrated superior performance, with ~27.5% higher ear-bearing tillers compared to CT. The ZT-based organic systems (OA-PNB, OA-PBB, OA-PFB) exhibited ~5.2% higher tiller numbers than CT but significantly lower than CA treatments. Number of grains per spike was also higher in CA treatments with ~20.1% higher values over the CT in 2022–23. For 2023–24, the highest grains per spike were observed in CA-PBB (66.6) with ~20.5% increase over CT, which recorded 55.3 grains per spike. Among the four production systems, CA-based treatments (CA-PNB, CA-PBB, CA-PFB) exhibited the significantly higher grains per spike with ~15.8% higher values compared to the CT system. The ZT organic systems (OA-PNB, OA-PBB, OA-PFB) showed significantly higher grains per spike values comparable to CT but notably lower than the CA treatments. However, 1000-grain weight did not vary significantly among the treatments.

The grain yield, stover yield and biological yield demonstrated significant differences across the year, whereas the harvest index showed no significant differences (Table 3). The CA based CA-PBB recorded the higher grain yield of 5.37 and 5.58 t/ha in 2022–23 and 2023–24, respectively, representing ~20.1 and 18.7% increase over CT (4.47 t/ha and 4.70 t/ha). Among the production systems, CA treatments (CA-PNB, CA-PBB, CA-PFB) demon-

Table 2. Yield attributing characteristics of wheat under different production system (pooled data of 2 years)

Treatment	Ear bearing tiller (No./m²)		Grains/spike		1,000-grain weight (g)	
	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24
‘CT’	427.5	423.0	54.6	55.3	40.3	41.1
‘CA-PNB’	504.0	514.5	53.0	51.4	39.8	38.2
‘CA-PBB’	547.5	567.5	60.2	66.6	40.5	40.9
‘CA-PFB’	499.5	524.5	65.6	59.6	40.8	41.2
‘OA-CT’	379.5	388.5	52.6	54.1	40.7	41.1
‘OA-PNB’	432.0	441.0	54.7	53.7	39.5	40.3
‘OA-PBB’	448.5	451.5	57.6	59.9	40.1	38.9
‘OA-PFB’	442.5	445.5	56.0	57.8	39.8	40.2
SEm±	22.0	11.7	1.3	1.0	0.7	0.7
CD (P=0.05)	66.7	35.5	4.1	3.1	NS	NS

CT, Conservation agriculture; CA-PNB, conservation agriculture permanent narrow bed; CA-PBB, conservation agriculture permanent broad bed; CA-PFB conservation agriculture permanent flatbed; OA-CT outperformed conservation agriculture; OA-PNB, Organic agriculture permanent narrow (PNB), broad; OA-PBB: Organic agriculture in permanent broad bed; OA-PFB: Organic agriculture in permanent flat bed

Table 3. Yield of wheat under different production system (pooled data of 2 years)

Treatment	Grain yield (t/ha)		Stover yield (t/ha)		Biological yield (t/ha)		Harvest index	
	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24
'CT'	4.47	4.70	7.05	7.18	11.52	11.88	0.39	0.40
'CA-PNB'	5.22	5.25	7.50	7.38	12.72	12.63	0.41	0.42
'CA-PBB'	5.37	5.58	7.76	7.70	13.13	13.28	0.41	0.42
'CA-PFB'	5.33	5.48	7.71	7.48	13.08	12.96	0.41	0.42
'OA-CT'	4.03	4.07	6.62	6.64	10.65	10.71	0.37	0.38
'OA-PNB'	4.04	4.12	6.62	6.72	10.66	10.84	0.38	0.38
'OA-PBB'	4.25	4.38	6.81	7.12	11.06	11.5	0.39	0.38
'OA-PFB'	4.22	4.26	7.01	6.85	11.23	11.11	0.39	0.39
SEm±	0.205	0.202	0.125	0.125	0.40	0.517	0.03	0.04
CD (P=0.05)	0.621	0.612	0.379	0.378	1.22	1.567	NS	NS

CT, Conservation agriculture; CA-PNB, conservation agriculture permanent narrow bed; CA-PBB, conservation agriculture permanent broad bed; CA-PFB conservation agriculture permanent flatbed; OA-CT outperformed conservation agriculture; OA-PNB, Organic agriculture permanent narrow (PNB), broad; OA-PBB: Organic agriculture in permanent broad bed; OA-PFB: Organic agriculture in permanent flat bed

strated a ~19.5% higher grain yield compared to the CT system. For biological yields also, CA-PBB showed the highest biological yield (13.13 & 13.28 t/ha) with ~14.0 & 11.8% higher values over CT in 2022–23 and 2023–24, respectively. Stover yield also showed significant variations, with CA-PBB recording the maximum yield in 2022-23 (7.76 t/ha) and 2023–24 (7.70 t/ha), which represented ~10.1% and ~7.2% improvements over CT in the respective years. Among the systems, conservation agriculture treatments showed a consistent advantage (~8.6% higher stover yield) compared to CT and ~12.4% more than organic systems. Improved soil physical, chemical, and biological characteristics in CA-based systems might have had a positive effect on crop growth by increasing the photosynthetic rate, and causing greater photosynthate translocation to sinks (Hazra *et al.,* 2019; Modak *et al.,* 2019). Moreover, permanent residue cover on soil surface under CA systems checks evaporation, which improves soil water balance, especially during hot and dry summer months, thereby resulting in enhanced crop growth and yields (Das *et al.,* 2018; Nath *et al.,* 2019).

Production Economics

The economic analysis of treatments across both years revealed significant differences among production systems in terms of cost of cultivation, gross returns, net returns, and Net B: C ratio (Table 4). The CA treatments (CA-PNB, CA-PBB, CA-PFB) consistently outperformed others in

Table 4. Profitability of wheat under different production system (pooled data of 2 years)

Treatment	Cost of cultivation ($\times 10^3$₹/ha)		Gross returns ($\times 10^3$₹/ha)		Net returns ($\times 10^3$₹/ha)		Benefit: cost ratio	
	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24
'CT'	47.2	50.3	111.2	121.4	64.0	71.1	1.35	1.41
'CA-PNB'	43.3	46.1	127.6	133.7	84.3	87.5	1.94	1.90
'CA-PBB'	43.4	46.2	131.4	141.7	88.0	95.6	2.03	2.07
'CA-PFB'	43.3	46.1	130.7	139.0	87.4	84.1	2.02	1.82
'OA-CT'	52.3	54.9	102.3	109.1	49.9	63.0	0.95	1.15
'OA-PNB'	46.7	49.1	101.3	107.5	54.5	58.5	1.17	1.19
'OA-PBB'	46.7	49.1	106.1	114.5	59.3	65.5	1.27	1.33
'OA-PFB'	46.7	49.1	104.8	110.7	58.1	61.6	1.24	1.26
SEm±	–	–	3.2	4.1	3.2	4.1	0.07	0.08
CD (P=0.05)	–	–	9.7	12.6	9.7	12.6	0.21	0.25

CT, Conservation agriculture; CA-PNB, conservation agriculture permanent narrow bed; CA-PBB, conservation agriculture permanent broad bed; CA-PFB conservation agriculture permanent flatbed; OA-CT outperformed conservation agriculture; OA-PNB, Organic agriculture permanent narrow (PNB), broad; OA-PBB: Organic agriculture in permanent broad bed; OA-PFB: Organic agriculture in permanent flat bed

economic parameters. In 2022–23, CA-PBB recorded the highest net return of 88.0 × 10^3 INR/ha with ~37.5% increase over CT (64.0 × 10^3 INR/ha). Similarly, in 2023–24, CA-PBB again achieved the maximum net return of 95.6 × 10^3 INR/ha, marking ~34.5% net returns compared to CT (71.1 × 10^3 INR/ha). Additionally, CA-PBB exhibited the highest Net B: C in both years, with 2.03 in 2022–23 and 2.07 in 2023–24, showing ~50.4% and ~46.8% improvement over CT, respectively. In contrast, organic systems, particularly the CT-based OA-CT, demonstrated the highest cultivation costs (52.3 × 10^3 INR/ha in 2022-23 and 54.9 × 10^3 INR/ha in 2023-24) but did not show higher gross and net returns. Among organic treatments, OA-PBB performed best, recording net returns of 59.3 × 10^3 INR/ha and 65.5 × 10^3 INR/ha in 2022–23 and 2023–24, respectively, but these were significantly lower than the CA-based treatments. However, all ZT-based organic treatments remained at par with each other. Overall, the conservation agriculture production systems (CA-PNB, CA-PBB, CA-PFB) led to higher gross and net returns with ~26.3% and ~47.3% higher values compared to CT and showed significantly higher gross and net returns compared to organic systems.

The study highlights the superior performance of conservation agriculture (CA) systems, particularly the CA-PBB treatment, in enhancing wheat growth, yield, and profitability across two years. CA systems consistently demonstrated higher growth parameters such as plant height, leaf area index, dry matter accumulation, and crop growth rate compared to conventional tillage (CT) and organic systems. The CA-PBB treatment exhibited the highest plant height (108.8 cm in 2023–24), dry matter accumulation (1435.9 g/m² in 2022–23), and crop growth rate (29.6 g/m²/day in 2022–23). Yield-attributing characteristics such as ear-bearing tillers and grains per spike were also significantly higher under CA systems. CA-PBB achieved the highest ear-bearing tillers (567.5/m² in 2023–24) and grains per spike (66.6 in 2023-24), with ~34.1% and ~20.5% increase over CT, respectively. Additionally, CA systems recorded higher grain, stover, and biological yields. Economic analysis showed that CA systems offered the highest profitability, with CA-PBB recording maximum net returns (95.6 × 10^3 INR/ha in 2023–24) and the highest Net B:C ratio (2.07). The enhanced performance of CA systems can be attributed to better soil health, enhanced nutrient availability, and optimized soil moisture conditions. Overall, conservation agriculture, particularly CA-PBB, emerged as the most effective system, delivering superior growth, yield, and economic benefits, making it a sustainable and efficient alternative to conventional and organic farming practices.

REFERENCES

Baghel, J.K., Das, T.K., Rana, D.S. and Paul, S. 2018. Effect of weed control on weed competition, soil microbial activity and rice productivity in conservation agriculture-based direct-seeded rice (Oryza sativa)-wheat (Triticum aestivum) cropping system. *Indian Journal of Agronomy* **63**(2): 129–136.

Bhattacharyya, R., Das, T.K., Sudhishri, S., Dudwal, B., Sharma, A.R., Bhatia, A. and Singh, G. 2015. Conservation agriculture effects on soil organic carbon accumulation and crop productivity under a rice–wheat cropping system in the western Indo-Gangetic Plains. *European Journal of Agronomy* **70**: 11–21.

Corbeels, M., De Graaff, J., Ndah, T.H., Penot, E., Baudron, F., Naudin, K., Andrieu, N., Chirat, G., Schuler, J., Nyagumbo, I. and Rusinamhodzi, L. 2014. Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture, Ecosystems & Environment* **187**: 155–170.

Das, T.K., Bandyopadhyay, K.K., Bhattacharyya, R., Sudhishri, S., Sharma, A.R., Behera, U.K. and Jat, M.L. 2016. Effects of conservation agriculture on crop productivity and water-use efficiency under an irrigated pigeon pea–wheat cropping system in the western Indo-Gangetic Plains. *The Journal of Agricultural Science* **154**(8): 1,327–1,342.

Das, T.K., Ghosh, S, Das, A., Sen, S., Datta, D., Ghosh, S. and Rana, D. S. 2021. Conservation agriculture impacts on productivity, resource-use efficiency and environmental sustainability: A holistic review. *Indian Journal of Agronomy* **66**: S111–S127.

Das, T.K., Nath, C.P., Das, S., Biswas, S., Bhattacharyya, R., Sudhishri, S., Raj, R., Singh, B., Kakralia, S.K., Rathi, N., Sharma, A.R., Dwivedi, B.S., Biswas, A.K. and Chaudhari, S.K. 2020. Conservation Agriculture in rice-mustard cropping system for five years: Impacts on crop productivity, profitability, water-use efficiency, and soil properties. *Field Crops Research* **250**: 107,781.

Das, T.K., Saharawat, Y.S., Bhattacharyya, R., Sudhishri, S., Bandyopadhyay, K.K., Sharma, A.R. and Jat, M.L. 2018. Conservation agriculture effects on crop and water productivity, profitability and soil organic carbon accumulation under a maize-wheat cropping system in the North-western Indo-Gangetic Plains. *Field Crops Research* **215**: 222–231.

Dwivedi, B.S., Shukla, A.K., Singh, V.K. and Yadav, R.L. 2003. Improving nitrogen and phosphorus use efficiencies through inclusion of forage cowpea in the rice–wheat systems in the Indo-Gangetic Plains of India. *Field Crops Research* **80**(3): 167–193.

Gamage, A., Liyanapathiranage, A., Manamperi, A., Gunathilake, C., Mani, S., Merah, O. and Madhujith, T. 2022. Applications of starch biopolymers for a sustainable modern agriculture. *Sustainability* **14**(10): 6,085.

Gathala, M.K., Kumar, V., Sharma, P.C., Saharawat, Y.S., Jat, H.S., Singh, M., Kumar, A., Jat, M.L., Humphreys, E., Sharma, D.K. and Sharma, S. 2013. Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the northwestern Indo-Gangetic Plains of India. *Agriculture, Ecosystems & Environment* **177**: 85–97.

Ghimire, R., Lamichhane, S., Acharya, B.S., Bista, P. and Sainju, U.M. 2017. Tillage, crop residue, and nutrient management effects on soil organic carbon in rice-based cropping systems: A review. *Journal of integrative agriculture* **16**(1): 1–15.

Hazra, K.K., Nath, C.P., Singh, U., Praharaj, C.S., Kumar, N., Singh, S.S. and Singh, N.P. 2019. Diversification of maize-wheat cropping system with legumes and integrated nutrient management increases soil aggregation and carbon sequestration. *Geoderma* **353**: 308–319.

Jat, R.K., Sapkota, T.B., Singh, R.G., Jat, M.L., Kumar, M. and Gupta, R.K. 2014. Seven years of conservation agriculture in a rice–wheat rotation of Eastern Gangetic Plains of South Asia: yield trends and economic profitability. *Field Crops Research* **164**: 199–210.

Modak, K., Ghosh, A., Bhattacharyya, R., Biswas, D.R., Das, T.K., Das, S. and Singh, G. 2019. Response of oxidative stability of aggregate-associated soil organic carbon and deep soil carbon sequestration to zero-tillage in subtropical India. *Soil and Tillage Research* **195**: 104,370.

Nath, C.P., Das, T.K., Bhattacharyya, R., Pathak, H., Paul, S., Chakraborty, D. and Hazra, K.K. 2019. Nitrogen effects on productivity and soil properties in conventional and zero tilled wheat with different residue management. *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences* **89**: 123–135.

Noulas, C., Herrera, J.M., Tziouvalekas, M. and Qin, R. 2018. Agronomic assessment of nitrogen use efficiency in spring wheat and interrelations with leaf greenness under field conditions. *Communications in soil science and plant analysis* **49**(7): 763–781.

Peigné, J., Ball, B.C., RogerEstrade, J. and David, C.J.S.U. 2007. Is conservation tillage suitable for organic farming? A review. *Soil Use and Management* **23**(2): 129–144.

Raj, R., Das, T.K., Ghosh, A., Govindasamy, P., Kumar, V., Babu, S. and Tiwari, G. 2022. Crop-establishment methods and weed management effects on weeds, wheat (Triticum aestivum) yield and economics under a conservation agriculture-based rice (Oryza sativa)–wheat system. *Indian Journal of Agronomy* **67**(4): 354–362.

Saad, A.A., Das, T.K., Rana, D.S. and Sharma, A.R. 2015. Productivity, resource-use efficiency and economics of maize (*Zea mays*)–wheat (*Triticum aestivum*)-greengram (*Vigna radiata*) cropping system under conservation agriculture in irrigated north-western Indo-Gangetic plains. *Indian Journal of Agronomy* **60**(4): 502–510.

Williams, D.M., BlancoCanqui, H., Francis, C.A. and Galusha, T.D. 2017. Organic farming and soil physical properties: An assessment after 40 years. *Agronomy Journal* **109**(2): 600–609.