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Comparative assessment of conventional, conservation, and organic agriculture for productivity and profitability of pigeonpea under pigeonpea (*Cajanus cajan*)-wheat (*Triticum aestivum*) system

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ABSTRACT

A study was carried out during 2022–23 and 2023–24 at ICAR-Indian Agricultural Research Institute, New Delhi to evaluate the impact of conventional agriculture (CT), conservation agriculture (CA), and organic agriculture (OA) on pigeonpea [*Cajanus cajan* L. (Millsp.)] under pigeonpea-wheat (*Triticum aestivum* L.) system. Conservation agriculture treatments such as CA_1, CA_2 and CA_3 (zero till permanent narrow bed (CA-PNB), permanent broad bed CA-PBB) and permanent flat bed (CA-PFB), respectively) outperformed CT and OA on growth parameters such as plant height, dry matter accumulation, leaf area index, crop growth rate and relative growth rate of pigeonpea. The pigeonpea variety selected for the experiment was Pusa Arhar 16. The experiment was laid out in a randomized block design (RBD) with 3 replications. Notably, CA_2 led to achieve greater plant height (129.3 cm and 132 cm) and dry matter accumulation (1143.7 g/m²) in both years. Enhanced nodulation in CA treatments suggested improved biological nitrogen fixation and soil health. Yield attributes under CA were significantly greater with CA_2 treatment, showing the highest pod numbers, grains/pod, and pod weight/plant. Grain yield in CA_2 was 24.3–30.5% higher than in CT and 30.1–36.8% higher than in OA_3. Economic analysis revealed that the cost of cultivation for CA treatments was marginally higher (8–9%) than CT, but gross returns for CA_1, CA_2 and CA_3 were substantially higher. CA_2 gave highest net returns with a 39% and 54% higher than over CT in the first and second years, respectively. Net B:C for CA_2 were also superior, showing a 27–40% improvement over CT over the years. It may be concluded that conservation agriculture, particularly CA_2, which provides better growth, higher yields and income would be economically superior to conventional and organic agriculture. This as well underscores the potential of CA to enhance pigeonpea productivity and farmers' income in upper and middle Gangetic plains of India.

Keywords: Benefit-cost analysis, Pigeonpea yield, Zero till permanent broad bed with residue, Zero till permanent flat bed with residue, Zero till permanent narrow bed with residue

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is an important crop for food security, a balanced diet, and poverty alleviation due to its versatile use as both food and fodder. In the country, pigeonpea is one of the main *kharif* (rainy season) legume crops, covering an area of 5.05 million hectares and contributing to a production of 4.34 million tonnes with a productivity of 859 kg/ha (MoA&FW 2022). The crop has been referred to as the second most important *kharif* grain legume after chickpea in India. Pigeonpea accounts for approximately 16% of the total area under pulse crops in the country. Beyond its nutritional significance, pigeonpea is also highly valuable in terms of diversifying the cropping cycle, reducing the ecological footprint, and improving soil health by bringing fallow lands under cultivation. The majority of pigeonpea cultivation in India, over 85%, is under rainfed conditions and the crop is often rotated with wheat in the pigeonpea-wheat cropping system under irrigated conditions, while it is grown as a sole crop in rainfed regions. The pigeonpea-wheat system is considered a potential alternative to the input-intensive and unsustainable rice-wheat cropping system prevalent in the Indo-Gangetic Plains (Arenjungla and Singh 2020). Previously, the use of long-duration pigeonpea varieties often delayed wheat sowing in the pigeonpea-wheat system even up to January and the wheat suffers from thermal heat stress at maturity, reducing crop yield (Ram *et al.* 2011). This issue can be addressed by using short-duration pigeonpea varieties such as Pusa Arahar-16, which allow for timely wheat sowing. Pigeonpea is in high demand

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in India as it provides high-quality protein, particularly important for the vegetarian population (Bhattacharjee *et al.* 2013). The increasing population has led to a reduction in the per capita availability of pulses (IIPR 2018). India is the largest importer of pigeonpea amounting to 674.44 million kg, with a 92.65% share of global imports in 2021. To reduce imports and achieve self-sufficiency in pigeonpea production, modifications in agro-techniques can significantly improve productivity and profitability through efficient use of land, moisture and solar energy (Kumar *et al.* 2016, Rajput and Bhadouriya 2019). The intensification of agriculture has led to the excessive use of pesticides and chemical fertilizers, negatively impacting soil biota, human health, and placing a heavy burden on farmers (Ramesh *et al.* 2005). Consequently, now the focus has been shifted towards non-chemical farming techniques to reduce environmental pollution, improve soil health, and create a sustainable farming system. However, the ability of these methods to feed the growing population and meet food demand is still questionable. Thus, the present work aims to explore the growth, yield attributes and yield of pigeonpea under different production systems i.e. conventional agriculture, conservation agriculture and organic agriculture.

MATERIALS AND METHODS

A study was carried out during 2022–23 and 2023–24 at ICAR-Indian Agricultural Research Institute, (28°38′23″ N, 77°09′27″ E and at an altitude of 228.61 m amsl) New Delhi. This region experiences a typical sub-tropical climate with an average annual precipitation of 670 mm. During the experimental period it received 1007.7 and 945.4 mm of rainfall, with 1125.4 and 1004.0 mm total pan evaporation, respectively. The experiment was laid out in a randomized block design (RBD) with three replications in an experimental plot size of 4.2 m × 9 m. Pigeonpea variety 'Pusa Arhar 16' was used for the experiment which is extra early maturing, semi-dwarf, determinate, high yielding variety with semi-erect compact plant type which allows timely sowing of wheat. Pigeonpea was sown during the second week of July both the years with a seed rate to 12 kg/ha. These encompassed three production system i.e. conventional agriculture (CT), conservation agriculture (CA) and organic agriculture (OA). The CA and zero tillage based OA systems comprised of different crops establishment methods such as zero till permanent narrow (PNB), broad (PBB) and flat (PFB) beds. The soil is Mollisols, specifically identified as Typic Haplustept, featuring a clay loam texture. Eight treatments were CT, CA_1 (CA-PNB), CA_2 (CA-PBB), CA_3 (CA-PFB), OA_1 (OA-TFB), OA_2 (OA-PNB), OA_3(OA-PBB) and OA_4 (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 (Fig. 1). Approximately 40% of the above-ground crop residues of wheat was retained in all CA plots. Recommended rates of 20 kg N, 26.2 kg P and 33.3 kg K/ha to pigeonpea 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 ~2.47 and 2.5 t/ha of FYM. The nutrient concentration of FYM was 0.79 and 0.81% N, 0.32 and 0.34% P and 0.44 and 0.48% 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 quizalofop-ethyl (50 g/ha), applied at 40 DAS. However, in organic treatments weeds were managed by manual weeding. For above-ground dry matter estimation, 5 plants

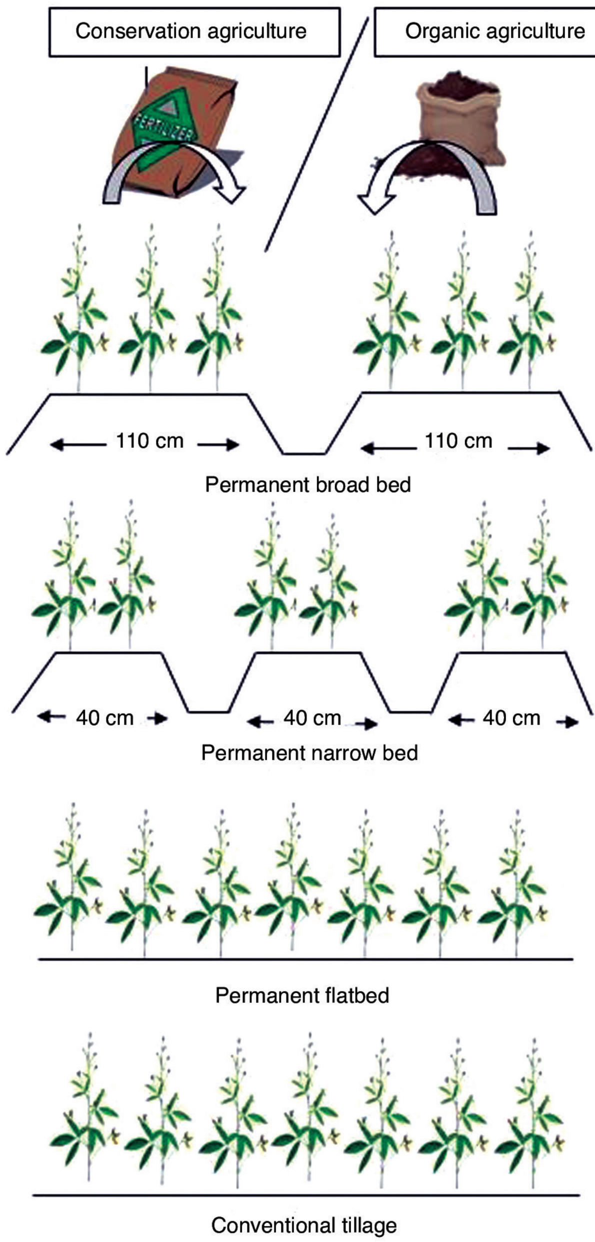

Fig. 1 Conceptual diagram of treatment details.

Table 1 Growth parameters of pigeon pea at 90 DAS under various production scenarios

Treatment	Plant height (cm)		Dry matter accumulation (g/m^2)		Leaf area index		Crop growth rate ($g/cm^2/day$)		Relative growth rate (mg/g/day)		No. of nodules/ plant	
	2022–2023	2023–2024	2022-2023	2023–2024	2022–2023	2023–2024	2022–2023	2023–2024	2022–2023	2023–2024	2022–2023	2023–2024
CT	120.3^{bcd}	125^{bcd}	1003.0^{bc}	983.7^{c}	3.54^{bc}	3.57^{b}	1.98^{c}	1.93^{d}	51.84^{c}	50.98^{a}	5.8^{f}	6.0^{f}
CA_1	128.7^{ab}	123^{cd}	1120.0^{a}	1130.4^{a}	3.76^{a}	3.68^{ab}	2.22^{a}	2.23^{a}	51.63^{a}	52.46^{b}	8.3^{c}	8.5^{c}
CA_2	129.3^{a}	132^{a}	1143.7^{a}	1146.7^{a}	3.79^{a}	3.77^{a}	2.26^{a}	2.29^{a}	51.88^{a}	52.21^{bc}	11.9^{a}	12.0^{a}
CA_3	128.7^{ab}	129^{ab}	1130.4^{a}	1131.9^{a}	3.76^{a}	3.76^{a}	2.23^{a}	2.22^{a}	51.27^{a}	51.89^{c}	8.7^{b}	9.0^{bc}
OA_1	123.3^{abcd}	121^{d}	968.9^{b}	951.1^{c}	3.64^{b}	3.65^{ab}	2.01^{bc}	2.00^{cd}	50.29^{a}	50.86^{d}	7.2^{e}	6.9^{e}
OA_2	117.0^{d}	113^{e}	1040.0^{b}	1043.0^{b}	3.53^{c}	3.55^{b}	2.05^{bc}	2.05^{bc}	51.63^{a}	51.75^{c}	7.6^{d}	7.8^{d}
OA_3	118.0^{cd}	109^{e}	1054.8^{b}	1060.7^{b}	3.54^{bc}	3.55^{b}	2.09^{b}	2.10^{b}	52.29^{a}	52.51^{b}	9.3^{b}	9.1^{b}
OA_4	126.3^{abc}	128^{abc}	1056.3^{b}	1051.9^{b}	3.54^{bc}	3.55^{b}	2.10^{b}	2.08^{bc}	52.13^{a}	53.03^{a}	7.3^{e}	7.1^{de}

Treatment details are given under Materials and Methods.

were randomly selected at 60 and 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 and relative growth rate were calculated as per Das (2008). Total number of pods/plant, grains/pod, pod weight/plant, grain weight/plant and 1000-grain weight were computed and calculated from 5 randomly selected plants at harvest. Economic parameters such as net returns and net B:C ratio were worked out using the standard procedure. Data were statistically analyzed using the analysis of variance (ANOVA) technique for randomized complete block design (RBD) (Gomez and Gomez 1984) and the least significant difference test was employed for separating the treatment means with a level of significance set at 5% and contrast analysis was done for grain yield under various production system.

RESULTS AND DISCUSSION

Pigeonpea growth parameters: The different production systems such as conventional tillage based system (CT), conservation agriculture (CA_1, CA_2, CA_3), conventional tillage based organic agriculture (OA-TFB) and zero tillage based organic agriculture (OA_1, OA_2, OA_3) significantly influenced plant height, dry matter accumulation, leaf area index, crop growth rate and relative growth rate of pigeonpea at 90 DAS (Table 1). The CA based CA_2 treatment showed significantly greater plant height than CT in both years, however, remained comparable with other CA based treatments. The plant height was maximum in CA_2 with 129.3 cm and 132 cm in 2022–23, and 2023–24, respectively. The CA_2 also had highest dry matter accumulation (1143.7 and 1146.7 g/m², respectively in 2022–23 and 2023–2024). With respect to dry matter accumulation of pigeonpea, all CA treatments (CA_1, CA_2 and CA_3) outperformed the CT and all OA treatments (OA_1, OA_2, OA_3 and OA_4) in both years. Similar trend was followed with respect to leaf area index and highest LAI was observed with the CA_2 treatment (3.79 and 3.77, respectively in 2022–23 and 2023–2024), closely followed by CA_1 (3.76 and 3.68) in both the years. The CA treatments consistently resulted in higher CGR values compared to CT and OA treatments. The CA_2 showed highest CGR (2.26 and 2.9 g/cm²/day in 2022–23 and 2023–24, respectively), closely followed by CA_3 and CA_1. Higher CGR values indicated the superior performance of these CA practices for promoting rapid crop growth and dry matter accumulation. Again, these CA_1, CA_2, and CA_3 had higher RGR than CT. Nodulation is crucial for biological nitrogen fixation in legumes, which can enhance soil fertility and crop productivity. The CA_2 and CA_3 consistently showed higher number of nodules/plant in both years (Table 1), might be higher root growth and development under CA_2 led to more nodules/plant. The consistently higher nodule numbers in CA highlighted their effectiveness in promoting biological nitrogen fixation and improving soil health. This apparently reflected better root growth of pigeonpea due to better aeration and good drainage, facilitating greater microbial activity with optimum moisture and nutrient availability for their growth (Jat and Ahlawat 2001, Rathore *et al.* 2010, Joshi *et al.* 2018). The practices like continuous zero tillage, residue retention, and controlled furrow irrigation adopted in these CA treatments might have played roles. The OA treatments also showed beneficial effects, although to a lesser extent than CA.

Pigeonpea yield attributes and yield: Conservation agriculture treatments, particularly CA_2, had significantly higher pod numbers compared to the control and most organic farming treatments. However, the lowest number of pods/plant was recorded in the OA_1 treatment (99.7). Conservation agriculture treatments (CA_2, CA_3) generally had higher numbers of grains/pod compared to the control and most organic farming treatments. The highest number of grains/pod was observed in the CA_2 treatment (4.3 and 4.6) in both the years. Highest values of pod weight/plant was generally observed in CA treatments, particularly CA_2 and CA_3, across both seasons. Similar trend was also followed in grain weight/plant also. Nevertheless, 1000-grain weight did not vary significantly across the treatments (Table 2). This suggests that these practices enhance reproductive success and yield potential, likely due to improved soil

Table 2 Yield attributing characteristics of pigeonpea under various production scenarios

Treatments	Pods/plant (No.)		Grains/pod (No.)		Pod weight/plant (g)		Grain weight/plant (g)		1000-seed weight (g)	
	2022–2023	2023–2024	2022–2023	2023–2024	2022–2023	2023–2024	2022–2023	2023–2024	2022–2023	2023–2024
CT	100.3^{c}	104.9^{cd}	3.9^{a}	4.0^{bc}	46.5^{c}	48.4^{d}	27.6^{c}	29.8^{b}	71.0^{a}	71.0^{a}
CA_1	111.3^{ab}	106.0^{c}	4.0^{a}	4.2^{b}	53.5^{b}	51.8^{c}	31.6^{ab}	34.6^{a}	71.0^{a}	71.0^{a}
CA_2	119.0^{a}	121.4^{a}	4.3^{a}	4.6^{a}	56.4^{ab}	59.4^{a}	34.2^{a}	35.5^{a}	70.7^{a}	71.7a
CA_3	111.7^{ab}	111.7^{b}	4.0^{a}	4.5^{a}	56.9^{a}	55.4^{b}	33.9^{a}	33.9^{a}	70.8^{a}	70.7a
OA_1	99.7^{c}	99.0^{e}	3.9^{a}	3.5^{de}	43.6^{cd}	43.6^{e}	27.4^{c}	25.3^{c}	70.9^{a}	71.7a
OA_2	102.7^{c}	100.8^{de}	3.7^{a}	3.4^{e}	43.1^{d}	43.7^{e}	26.5^{c}	24.8^{c}	70.3^{a}	71.0a
OA_3	101.7^{c}	104.7^{cd}	3.9^{a}	3.9^{bc}	43.9^{cd}	47.6^{d}	28.1^{c}	30.1^{c}	70.3^{a}	71.7a
OA_4	104.7^{bc}	102.7^{cde}	4.0^{a}	3.8^{cd}	44.1^{cd}	44.8^{e}	29.1^{bc}	26.7^{c}	70.3^{a}	71.0a

Treatment details are given under Materials and Methods.

health and nutrient availability (Das *et al.* 2016). This improvement underscores the potential of conservation agriculture in optimizing yield components crucial for overall crop productivity. Overall, yield improvement was recorded in the second year compared to first year (Fig. 2). The highest grain yield was observed in the CA_2 treatment (1.67 and 1.80 t/ha in 2022–23 and 2023–24, respectively). Conservation agriculture treatments (CA_1, CA_2, CA_3) showed higher grain yields compared to the CT and organic farming treatments. On average, the CA treatments showed ~24.3–30.5% improvement in grain yield compared to CT, whereas, ~30.1–36.8% compared to OA_3. Biological yield also followed the similar trend. Conservation agriculture, due to higher water and nutrient use efficiency, lower soil evaporation, increased access to nutrients and improved soil physical environment led to accumulation of organic carbon in soil resulted in higher yield and yield attributing characteristics of pigeonpea (Das *et al.* 2018 and 2021). The contrast analysis (Table 3) between the three production systems showed significant difference among the conventional, conservation and organic agriculture. Conservation agriculture with residues acted as a protective layer, conserving moisture and improving organic matter, and fostering nutrient cycling and availability to

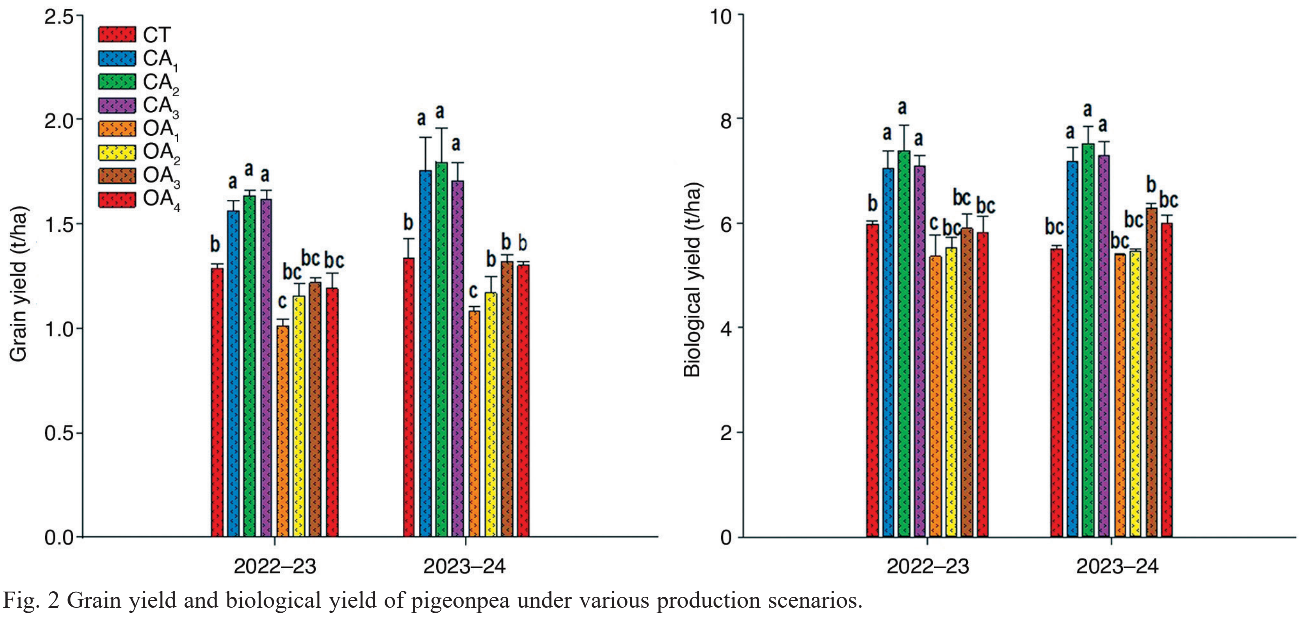

Fig. 2 Grain yield and biological yield of pigeonpea under various production scenarios.
Treatment details are given under Materials and Methods.

Table 3 Contrast analysis of economic yield between various production scenarios

Economic yield between various production scenarios					
Contrast	Contrast SS	F Value	Pr>F	Significant	Per cent increase or decrease
Conservation agriculture vs Conventional agriculture	0.2272	56.57	<.0001	**	~27.5% (1.68 t/ha vs 1.32 t/ha)
Conventional agriculture vs Organic farming	0.0252	6.28	0.0252	*	~11.6 % (1.32 t/ha vs 1.18 t/ha)
Conservation agriculture vs Organic farming	0.9084	226.16	<.0001	**	~42.2 % (1.68 t/ha vs 1.18 t/ha)

** - Significant at 1%; * - Significant at 5%; NS, Non-Significant.

crops, which are crucial for sustaining crop growth (Jat *et al.* 2019, Roy *et al.* 2023). The organic treatments with N equivalent amount of FYM application might not supplied sufficient amount of nutrient to the crop, thereby reducing growth and yield of pigeonpea. The CT system that involves intensive tillage (without residue) results in loss of carbon and other nutrients (Nandan *et al.* 2019), and surface soil loses moisture rapidly through evaporation, resulting in poor crop germination/stands and lower crop yield (Das *et al.* 2018).

Economics: The data on the economic analysis of various agricultural treatments revealed that the cost of cultivation was increased by 4.6% for most treatments from 2022–23 to 2023–24 (Supplementary Table 1). The highest costs were observed in the OA_1 treatment (43,000 and 44,700 ₹/ha, respectively for 2022–23 and 2024) for both seasons followed by CA-based treatments (CA_1, CA_2, CA_3). The higher cost of cultivation in OA_1 is due to expensive tillage operation while higher cost of cultivation in CA treatments is mainly due cost of wheat residue. CA treatments generally had 8–9% higher cultivation costs compared to CT. Gross returns for CA_1, CA_2, and CA_3 were significantly higher compared to the control and organic farming treatments. The highest gross returns were observed in the CA-PBB treatment for both years. Net returns of conservation agriculture treatments (CA_1, CA_2, CA_3) were significantly higher compared to the control and organic farming treatments with 39 and 54% higher net returns in CA_2 than CT in first and second season, respectively. Similarly, the net B:C was highest in CA_2 treatment for both season with ~27 and 40% higher values than CT in 2022–23 and 2023–24, respectively. Therefore, conservation agriculture practices being economically superior, recorded higher profitability and better return on investment compared to conventional farming methods and organic farming practices.

The comparative analysis of pigeonpea under conventional, conservation, and organic production systems over two consecutive growing seasons reveals that conservation agriculture (CA) practices significantly outperform conventional agriculture (CT) and organic farming (OA) methods in various growth parameters, yield attributes and economic returns. Conservation agriculture treatments, especially CA_2 and CA_3, consistently showed higher plant height, dry matter accumulation, leaf area index, crop growth rate and relative growth rate. These treatments also promoted better nodulation, enhancing biological nitrogen fixation and soil fertility. In terms of yield attributes, CA treatments, particularly CA_2, resulted in significantly higher pod numbers, grains/pod, pod weight and grain weight/plant. This led to substantial improvements in grain and biological yield, with CA_2 achieving the highest yields in both seasons. Economic analysis further supports the superiority of CA practices. Although the cost of cultivation was slightly higher in CA treatments, the gross returns, net returns and net B:C were significantly better compared to CT and OA treatments. CA_2 demonstrated the highest profitability. Overall, conservation agriculture practices not only enhance growth and yield attributes of pigeonpea but also provide higher economic returns, making them a more sustainable and profitable option compared to conventional and organic farming methods.

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