



Production Potential of Pigeonpea (*Cajanus cajan* L.) under Conservation Agriculture based Tillage, Residue and Weed Management Practices

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ABSTRACT

Background: Conservation agriculture (CA) is widely acknowledged as a powerful technique for addressing land and environmental degradation. CA is based on principles of maintenance of a permanent soil cover, minimum soil disturbance and diversification of plant species. A long term experiment was conducted to assess the effect of conservation agriculture practices on performance of pigeonpea. The experiment was started in *Rabi* 2018-19 which was later modified in *Rabi* 2021-22 with different tillage, residue, weed and nutrient management practices under diversified cropping systems.

Methods: The present investigation was conducted in *Kharif* 2022 and 2023. The experiment was laid out in randomised complete block design comprising 3 treatments including layering of tillage practices comprised of sowing of pigeonpea on fresh bed and permanent bed, the 3 residue management practices were residue removal, residue incorporation and surface residue retention while 2 weed management practices involved application of pre-emergence herbicides and cowpea green manuring coupled with 2 nutrient management practices viz. recommended dose of fertilizer and 80% recommended dose of nitrogen (RDN) in pigeonpea.

Result: Significantly higher growth parameters, nodule dry weight, pods plant⁻¹, yield and nutrient uptake were recorded in no-tillage with surface residue retention under cowpea green manuring along with application of 80% RDN. Thus, conservation agriculture based no-till scenario can be adopted for maximizing productivity of pigeonpea.

Key words: Conservation agriculture, Nutrient uptake, Pigeonpea, Productivity.

INTRODUCTION

Conservation agriculture (CA) is widely acknowledged as a powerful technique for addressing land and environmental degradation. CA is based on principles of maintenance of a permanent soil cover, minimum soil disturbance and diversification of plant species. To address the problem of progressive deterioration in the soil organic carbon due to degradation of soil structure, accelerated oxidation and loss of valuable plant nutrients, some of the agronomic practices like zero tillage, reduced tillage or minimum tillage are the potential resource conservation technologies that can play a big role in preserving the natural resource base. Farmers of IGP are also retaining crop residue with the help of machines like "Happy Seeder" which directly drill seed and fertilizer in soil through the previous crop residue (Sidhu *et al.*, 2015) hence, gradually moving towards conservation agriculture based cropping systems. Diversifying rice-wheat system with pigeonpea-wheat system addresses the challenges of declining soil organic carbon status and environmental trade-offs (Yadav *et al.*, 2017). Pigeonpea (*Cajanus cajan* L.) also called as Arhar or Tur is an important legume crop of the Indian subcontinent, Southeast Asia and East Africa grown predominantly under rainfed conditions (Sarkar *et al.*, 2018, Bansal *et al.*, 2024). With its leguminous characteristics of biological N fixation, deep roots, low external input requirement, profuse leaf fall, *etc.* pigeonpea is becoming

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dominant during rainy season which could be followed by staple cereal *i.e.* wheat making the cropping system (pigeonpea-wheat) stable and remunerative. More than 85 per cent of the world pigeonpea is produced and consumed in India, where it is a key crop for food and nutritional security of the people. In India, the area under pigeonpea cultivation has increased to 4900 thousand hectare in 2021-22 from 4724 thousand hectare in 2020-21 and 4532 thousand hectare in 2019-20. In Punjab, it covers an area of about 1.40 thousand hectare with total production

and productivity of 1.42 thousand tones and 1014 kg ha⁻¹, respectively (Anonymous, 2022). The promotion of the high density planting method with introduction of short duration and early maturing varieties of pigeonpea is anticipated to enhance pulses productivity, leading to an increase in acreage (Anonymous, 2020). Unlike rice, pigeonpea crop introduced positive effects on root volume and root weight of succeeding wheat (Singh *et al.*, 2005; Hazra *et al.*, 2020). Diversifying rice-wheat system with pigeonpea-wheat system addresses the challenges of declining soil organic carbon status and environmental trade-offs under increasing climate vagaries and erratic rainfall patterns with climate change (Saha *et al.*, 2025). In conservation agriculture, weeds can be controlled both manually as well as by herbicide application. Since human labor is often expensive and is rarely available during critical periods of crop weed-competition thereby making herbicides the most viable option for weed control in conservation agriculture. Herbicides are widely employed in conservation agriculture for controlling weeds; however, a single herbicide cannot be effective against a diversity of weed flora present in fields. Hence, integrated weed management comprising the use of crop residues as mulch, green manures, stale seedbed technique, controlled use of herbicides and following recommended crop rotation can be the most desirable strategy for effective weed control in conservation agriculture. Therefore, an investigation was conducted to evaluate the long term effect of conservation agriculture on productivity of pigeonpea under pigeonpea-wheat cropping system.

MATERIALS AND METHODS

A long term field trial was conducted at Punjab Agricultural University, Ludhiana. The experiment was started during *Rabi* 2018-19 with different conventional and conservation agriculture based tillage and residue management scenarios. Later on the experiment was modified with different tillage, residue, weed and nutrient management practices under conventional and conservation agriculture. The modified layout was established during *Rabi* 2021 as zero cycle with wheat crop in order to ensure residue

availability for first year of trial and the actual treatments were imposed in *Kharif* 2022. The experiment was conducted during 2022-23 and 2023-24. The experimental site was located at 30°54'N latitude and 75°48'E longitude at an elevation of 247 meters above mean sea level. The site in general is bestowed with hot and dry summers followed by hot and humid monsoon season and cold winters. The experiment was laid out in randomized complete block design with three replications and three treatments involving layering of different cropping systems, tillage, residue, weed and nutrient management practices. Each plot was 135 m² (18 × 7.5) m. The tillage practices in pigeonpea comprised of sowing of pigeonpea on fresh bed and permanent bed, the 3 residue management practices were residue removal, residue incorporation and surface residue retention while 2 weed management practices involved application of pre and post-emergence herbicides and cowpea green manuring coupled with 2 nutrient management practices viz. recommended dose of fertilizer and 80% recommended dose of nitrogen in pigeonpea (Table 1). The soil of the experimental site was sandy loam in texture, normal in reaction, low in available nitrogen but medium in organic carbon, available phosphorus and potassium with electrical conductivity in the safer range. Pigeonpea variety AL 882 was sown in the experiment. Pigeonpea was sown with bed planter on top centre of freshly prepared beds at a spacing of 67.5 × 18 cm whereas, in case of permanent beds under no tillage with residue retention scenarios, the seed was sown using double disc planter maintaining spacing of (67.5 × 18) cm. Around 1.65 to 1.70 t ha⁻¹ pigeonpea leaf litterfall and 1.6 to 1.7 t ha⁻¹ wheat straw residue was either incorporated or retained on surface in the succeeding crop of respective crop rotation as per technical programme of work.

Among different weed management practices, glufosinate ammonium @ 2.25 litres ha⁻¹ using 250 litres of water was sprayed in no-till scenarios with residue retention before sowing of the crops. Pendimethalin 30 EC was sprayed as pre-emergence herbicide at the same day of sowing @ 2.5 litres ha⁻¹ in 500 litres water in pigeonpea crop. In green manuring scenario, cowpea was sown as

Table 1: Treatment details.

Cropping systems	Residue management <i>Kharif</i> <i>Rabi</i>	Abbreviation	Weed management in pigeonpea	Nutrient management in Pigeonpea
Pigeonpea on fresh bed - Conventional tillage wheat	R0: Residue removed	FBP - CTW (R0)	PAU recommendation (Pre -em herbicides)	PAU recommendation
Pigeonpea on fresh bed - Super seeder sown wheat	RI: Residue incorporation (20-25% Wheat residue - 100 % Pigeonpea litterfall residue)	FBP - SSW (RI)	Cowpea cover crop + Pre-em herbicides	PAU recommendation
Pigeonpea on permanent beds - No tillage wheat	SRR: Surface residue retention (20-25% Wheat residue - 100% Pigeonpea litterfall residue)	PBP - NTW (SRR)	Cowpea cover crop + Pre-em herbicides	80% Recommended dose of nitrogen (RDN)

cover crop at the time of sowing of pigeonpea. Cowpea was harvested manually at 30 DAS and the residue was used as surface mulch. The crops were grown under assured irrigation without any water stress during crop growth period and were managed as per regional recommendations of PAU.

Data on various growth parameters viz. plant height, dry biomass, leaf area index (LAI), number of branches plant⁻¹ and interception of photosynthetically active radiation (IPAR) along with symbiotic traits including number of nodules plant⁻¹ and nodules dry weight plant⁻¹ were recorded at 90 days after sowing for studied scenarios. For plant height, 10 plants were selected randomly, tagged and measured in cm. While for dry biomass accumulation, half meter row length from penultimate row of the plot from two spots were taken which were later oven dried at 70°C for 72 hours. The Sun Scan Canopy Analyzer (Model: Sun Scan type SS1, Manufactured by Delta-T Devices, Cambridge- England) was used to record the leaf area index of different crops between 12 pm to 2 pm. While the IPAR readings were taken using a line Quantum Sensor. The incoming and reflected radiations were measured at 1m above crop canopy while transmitted radiations were measured at the base of crop plant in the range of 400-700nm wavelength. The readings were taken on selected days during clear sky. Data collected from this observation was used to calculate the interception of PAR (%) by the crop by using formula given as under:

$$\text{Interception of PAR (\%)} = \frac{\text{IPAR} - (\text{TPAR} + \text{RPAR})}{\text{IPAR}} \times 100$$

Where,

IPAR = Incoming PAR above the canopy (W m⁻²).

TPAR = Transmitted PAR to the ground (W m⁻²).

RPAR = Reflected PAR from the canopy (W m⁻²).

Observations on symbiotic traits were recorded by gently uprooting the selected plants from soil followed by washing of roots under water and then separation of nodules. The separated nodules were counted for obtaining number of nodules plant⁻¹ and then oven dried to obtain their dry weight plant⁻¹. Data pertaining to yield and yield attributes was obtained at harvest. Yield attributes viz. pods plant⁻¹, pod length and number of seeds pod⁻¹ were counted from randomly selected plants from the plot whereas, a sizeable sample of seeds was taken randomly for counting 100 seeds from the bulk produce of each plot and thereafter, 100 seed weight was recorded in g (grams). From the individual plot, the crop was harvested and subsequently, the seed, sticks, husk and biological yield thus obtained were weighed and expressed in kg ha⁻¹. For calculating the nutrient uptake in seed and stover of pigeonpea, the samples of seed and stover were taken at harvest. These samples were first sundried and then oven dried at 65°C till a constant weight was reached. The grain samples were finely ground in a small grinding mill while the straw samples were finely ground in a Wiley Mill. These finely ground samples were passed through a sieve of 32

mesh size. These seed and stover samples were used for estimating the nitrogen, phosphorus and potassium content. The nutrient uptake viz. nitrogen (N), phosphorus (P) and potassium (K) was calculated by multiplying the percent nutrient content (NPK) of seed and stover sample with its respective seed yield and stover yield and was expressed as kg ha⁻¹. For statistical analysis the data were subjected to ANOVA and treatment means were compared using Fisher's protected LSD test at the 0.05 probability level using R software.

RESULTS AND DISCUSSION

Growth parameters

Growth parameters (Table 2) viz. plant height, dry biomass accumulation, leaf area index (LAI), number of branches plant⁻¹ and interception of photosynthetically active radiation (IPAR) were significantly affected by different tillage, residue, weed and nutrient management practices. No-tillage with surface residue retention under cowpea green manuring and application of 80% RDN (Sc₂) recorded significantly higher plant height (137.35 cm and 139.85 cm), dry biomass (316.11 g m⁻² and 337.79 g m⁻²), LAI value (7.87 and 7.97), number of branches plant⁻¹ (17.04 and 18.52) and IPAR value (93.6 and 96.3) of pigeonpea in pigeonpea-wheat cropping systems during both the years of investigation, respectively. The increment in growth of crop might be attributed to continuous and slow release of nutrients from the decomposing residue retained on the soil surface which created a better nutritional habitat for plant growth during active vegetative growth stages. This might have resulted to increase in cell multiplications, expansion and elongation in the plant system which ultimately enhanced the plant height and leaf area. The continuous supply and adequate amount of nutrients resulted in sufficient synthesis of photosynthates which boost the metabolic processes, increase cell division and rapid formation of meristematic tissues, more number of functional leaves per plant that consequently enhanced the leaf area index (Thomas *et al* 2007, Kumar *et al* 2018). Leaf area is directly related to photosynthetic rate and ultimately photosynthetically active radiation. Higher leaf area index might have resulted in higher interception of photosynthetically active radiation. Similar results were also reported by (Kumar *et al* 2018, Iqbal *et al* 2021, Gawdiya *et al* 2022). The increase in dry biomass accumulation might be due to more leaf area, greater number of leaves, number of primary and secondary branches as well as higher nutrient uptake by crop resulting in higher photosynthetic efficiency and ultimately higher photosynthate accumulation. The decomposing residue under undisturbed field might have improved soil conditions and promoted plant growth.

Symbiotic traits

Symbiotic traits viz. number of nodules plant⁻¹ and nodule dry weight plant⁻¹ (Table 3) is an important parameter for assessing the nitrogen fixing capacity of leguminous

Table 2: Effect of conventional tillage and conservation agriculture practices on growth parameters of pigeonpea during Kharif season.

Scenario	Growth parameters														
	Plant height (cm)			Dry biomass (g m ⁻²)			Leaf area index			Branches plant ⁻¹			IPAR*		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Sc1: FBP-CTW (R0)	125.43	126.48	125.95	250.40	277.13	263.76	7.03	7.11	7.07	12.93	14.19	13.56	83.1	85.7	84.40
Sc2: FBP-SSW (R1)	131.84	134.52	133.18	290.25	311.63	300.94	7.79	7.88	7.84	15.37	16.76	16.07	91.7	94.2	92.97
Sc3: PBP-NTW (SRR)	137.35	139.85	138.60	316.11	337.79	326.96	7.87	7.97	7.92	17.04	18.52	17.73	93.6	96.3	94.97
SD (p=0.05)	8.01	8.42	5.83	49.21	44.74	28.71	0.69	0.70	0.62	2.29	2.86	1.84	8.27	8.35	4.27

*IPAR-Interception of photosynthetically active radiation

plants. The data revealed that number of nodules plant⁻¹ was not affected significantly under different tillage and crop management scenarios. However, dry weight of root nodules of pigeonpea was significantly affected under no-tillage with surface residue retention along with cowpea green manuring and application of 80% RDN (Sc₃) over that of conventional tillage of pigeonpea without crop residue (Sc₁) under pigeonpea-wheat cropping systems during both the years of investigation. The study found only weak evidence that nodulation (number of nodules plant⁻¹) was improved under CA management compared to CT as the differences were not statistically significant (Binacchi *et al.*, 2022). However, reduced tillage has been reported to enhance nodule dry weight plant⁻¹ which might be attributed to pigeonpea + cowpea intercropping. Cowpea is a promiscuous legume due to the large number of genera of rhizobium bacteria that can establish root nodules (Ndungu *et al.*, 2018). Therefore, while incorporation of cowpea as green manure crop might have caused relocation of rhizobium from decaying cowpea nodules towards developing pigeonpea nodules which considerably enhanced the rhizobium population in pigeonpea rhizosphere and ultimately increased the size of developing nodules of pigeonpea. The promiscuous nature of cowpea intercropped with pigeonpea could have led to pigeonpea to respond well to inoculation in the field. Besides this, the addition of crop residue in soil lead to accumulation of organic matter in soil that increased the SOC content in residue retained plots, which served as food material for microbes thus leading to increased microbial population (Xiao *et al.*, 2021). Higher number of micro-organisms and lesser soil disturbance could also be the probable reason for improvement in dry weight of nodules plant⁻¹ under no tillage plots.

Yield attributes

Various yield attributes of pigeonpea crop including number of pods plant⁻¹, pod length, number of seeds pod⁻¹ and 100-seed weight (Table 4) were influenced by different tillage, residue, weed and nutrient management practices under conservation agriculture. Significantly higher number of pods plant⁻¹ (136.97 and 139.83) in pigeonpea were recorded in no-tillage with surface residue retention under green manuring of cowpea and application of 80% RDN (Sc₂) during *Rabi* 2022-23 and 2023-24, respectively. Pod length, number of seeds pod⁻¹ and 100-grain weight showed no significant difference across different tillage, residue, weed and nutrient management practices under conservation agriculture. The increase in yield attributes might be attributed to favourable effect on root development, metabolic activities and energy transformation in plant system which ultimately caused higher translocation of photosynthates towards the sink development due to better source-sink relationship (Kumar *et al.*, 2018).

Crop yield

Crop yield viz. seed yield, sticks yield, husk yield and biological yield (Table 5) were recorded significantly

higher in no-tillage with surface residue retention under cowpea green manuring and application of 80% RDN (Sc_3). There was 28.70 per cent and 24.06 per cent increment in seed yield, 19.63 per cent and 17.55 per cent increase in stick yield while the biological yield increased by 23.35 per cent and 20.36 per cent under no-tillage scenario (Sc_3) over that of conventional tillage scenario (Sc_1) during *Kharif* season of the year 2022 and

2023, respectively. The crop yields might have increased due to optimum nutrient availability at critical crop growth stage which enhanced the crop growth, development and yield attributes. The improvement in crop yield might also be linked to the cumulative effects of additional nutrients supplied through crop residue decomposition (Blanco-Canqui and Lal, 2009; Kaschuk *et al.*, 2010), reduced weed competition (Ozpinar 2006, Chauhan *et al.*, 2007),

Table 3: Effect of conventional tillage and conservation agriculture practices on symbiotic traits of pigeonpea during *Kharif* season.

Scenario	Symbiotic traits					
	Nodules plant ⁻¹ (No.)			Nodule dry weight (mg plant ⁻¹)		
	2022	2023	Pooled	2022	2023	Pooled
Sc 1: FBP-CTW (R0)	24.01	23.84	23.93	41.27	40.40	40.84
Sc 2: FBP-SSW (RI)	24.75	25.51	25.13	46.49	46.73	46.61
Sc 3: PBP-NTW (SRR)	25.24	25.97	25.60	49.10	48.61	48.85
LSD (p=0.05)	NS*	NS	NS	5.90	6.40	3.51

*NS- Non significant at p=0.05.

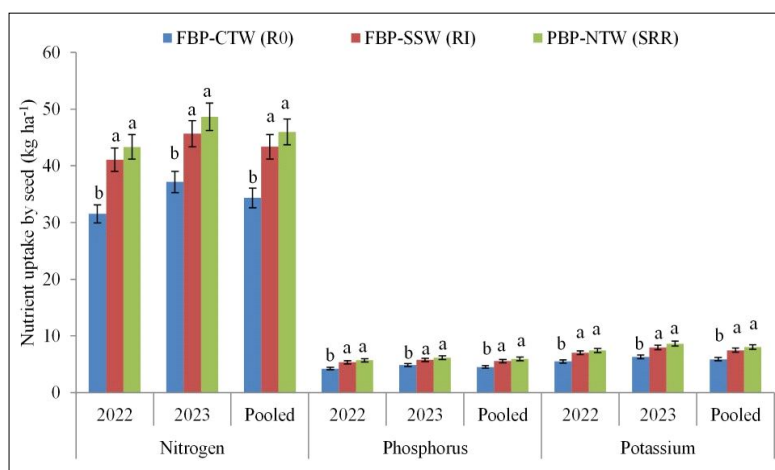


Fig 1: Effect of conventional tillage and conservation agriculture practices on nutrient uptake by pigeonpea seed during *Kharif* season.

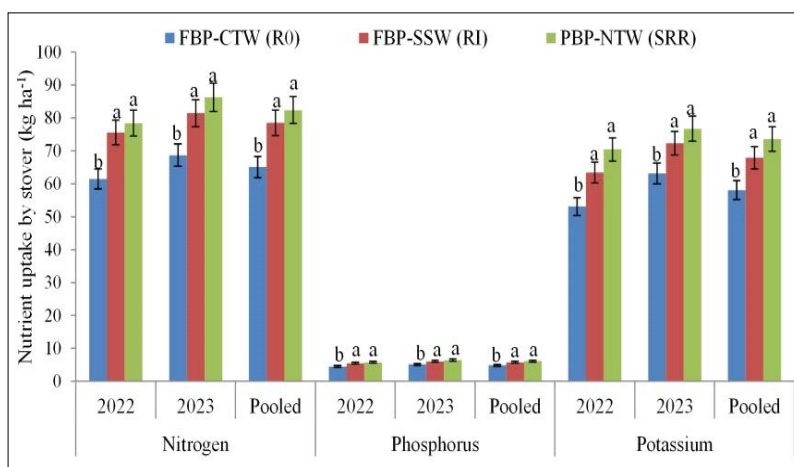


Fig 2: Effect of conventional tillage and conservation agriculture practices on nutrient uptake by pigeonpea stover during *Kharif* season.

Table 4: Effect of conventional tillage and conservation agriculture practices on yield attributes of pigeonpea during *Kharif* season.

Scenario	Yield attributes											
	Pods plant ⁻¹ (No.)			Pod length (cm)			Seeds pod ⁻¹ (No.)			100-seed weight (g)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Sc 1: FBP-CTW (R0)	120.15	122.14	121.14	4.27	4.41	4.34	3.72	3.84	3.78	6.72	6.86	6.79
Sc 2: FBP-SSW (R1)	134.63	136.99	135.81	4.52	4.95	4.74	4.07	4.25	4.12	6.99	7.01	7.00
Sc 3: PBP-NTW (SRR)	136.97	139.83	138.40	4.74	5.17	4.96	4.15	4.41	4.28	7.03	7.19	7.11
LSD (p=0.05)	13.48	14.02	7.26	NS*	NS	NS	NS	NS	NS	NS	NS	NS

*NS- Non significant at p=0.05.

Table 5: Effect of conventional tillage and conservation agriculture practices on yield and harvest index of pigeonpea during *Kharif* season.

Scenario	Seed yield (kg ha ⁻¹)			Sticks yield (kg ha ⁻¹)			Husk yield (kg ha ⁻¹)			Biological yield (kg ha ⁻¹)			Harvest index (%)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Sc 1: FBP-CTW (R0)	1014	1143	1079	2950	3208	3079	687	787	737	4651	5138	4895	21.80	22.25	22.03
Sc 2: FBP-SSW (RI)	1256	1347	1302	3458	3642	3550	861	934	898	5575	5923	5749	22.53	22.74	22.64
Sc 3: PBP-NTW (SRR)	1305	1418	1362	3529	3771	3650	903	995	949	5737	6184	5961	22.75	22.93	22.84
LSD (p=0.05)	183	208	103	452	439	249	145	154	81	776	809	510	NS*	NS	NS

*NS- Non significant at p=0.05.

enhancement in soil physical health (Jat *et al.*, 2021), increase in soil carbon (Kaiser *et al.*, 2014, Parihar *et al.*, 2016). Undisturbed scenario under residue retention marked improvement in soil physico-chemical and biological properties due to ensured nutrient availability to the plant at the critical crop growth period hence, contributing towards all-round crop growth and development, which consequently resulted in increased yield (Kumar and Yadav, 2018, Kar *et al.*, 2021).

Nutrient uptake

The perusal of data on nutrient uptake viz. nitrogen (N), phosphorus (P) and potassium (K) by pigeonpea seed (Fig 1) and stover (Fig 2) showed significant differences among different tillage, residue, weed and nutrient management practices. The data revealed that no-tillage in permanent bed pigeonpea under surface residue retention with cowpea green manuring and application of 80% nitrogen (Sc₃) recorded significantly higher nitrogen uptake (43.33 and 48.64 kg ha⁻¹), phosphorus uptake (5.72 and 6.18 kg ha⁻¹) and potassium uptake (7.44 and 8.65 kg ha⁻¹) by pigeonpea seed which was found statistically at par with conventional tillage in fresh bed pigeonpea under residue incorporation with cowpea green manuring during *Kharif* 2022 and 2023. Similarly, significantly higher nitrogen uptake (78.45 and 86.26 kg ha⁻¹), phosphorus uptake (5.81 and 6.43 kg ha⁻¹) and potassium uptake (70.47 and 76.73 kg ha⁻¹) by pigeonpea stover was observed in permanent bed pigeonpea under surface residue retention with cowpea green manuring and application of 80% nitrogen (Sc₃) during *Kharif* 2022 and 2023 respectively. Addition of organic matter in the form of crop residues might have increased the soil physico-chemical and biological properties of soil which resulted in better availability of soil macro and micro nutrient due to slow release of nutrients from decomposing soil residue. This might have increased the nutrient content in plant seed and stover causing better assimilation of photosynthates ultimately increasing the yield. The increase in grain yield with increasing nutrient availability was supported by higher dry matter accumulation and better yield attributing characters, which helped in accumulating more NPK in the seed and stover. Kachroo and Razdan (2006) also reported similar results.

CONCLUSION

This study highlights that importance of conservation agriculture based no-tillage scenario in pigeonpea-wheat cropping system. It is concluded from the study that no-tillage in pigeonpea with surface residue retention, coupled with cowpea green manuring and application of 80% RDN, is an effective approach for enhancing growth, productivity and nutrient uptake of pigeonpea under pigeonpea-wheat cropping systems. Conservation agriculture can play a pivotal role in maximizing pigeonpea production in Trans-Gangetic plains of India.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish or preparation of the manuscript.

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