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Production Potential of Timely Sown Pigeonpea (*Cajanus cajan* L.) in Pigeonpea-*Gobhi Sarson*-Summer Moong Cropping System

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ABSTRACT

Background: Diversification of the rice-wheat system in Punjab is essential to address declining soil fertility, groundwater depletion and residue management issues. The pigeonpea-*gobhi sarson*-summer moong cropping system offers a promising and sustainable alternative by improving soil health, resource-use efficiency and profitability. Pigeonpea being a deep-rooted legume contributes to soil nitrogen enrichment, while *gobhi sarson* and summer moong efficiently utilizes residual fertility during the succeeding seasons. Timely sowing plays a vital role in ensuring better establishment and higher productivity of pigeonpea.

Methods: The study was conducted during *Kharif* 2023 and 2024 at the Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana, using a randomized complete block design (RCBD) with three replications. Eight treatments included pigeonpea (PAU 881 and AL 882) + cowpea (F) - *gobhi sarson* (relay cropping/direct sowing/transplanting) - summer moong during the *Kharif-Rabi-Zaid* season. Pigeonpea was sown on ridges 67.5 cm spacing with cowpea intercropped in the furrows. Observations were recorded on growth, symbiotic traits, yield attributes, yield and nutrient uptake to evaluate the production potential of timely sown pigeonpea in pigeonpea-*gobhi sarson*-summer moong cropping system.

Result: Significantly higher growth parameters, nodule dry weight, pods plant^{-1}, yield and nutrient uptake of pigeonpea were recorded under pigeonpea (AL 882) + cowpea (F) - *gobhi sarson* (relay cropping) - summer moong (T_4). The higher productivity in T_4 was attributed to improved canopy development and enhanced soil fertility dueto legume. This pigeonpea based diversified cropping system can be promoted as a sustainable and resource-efficient option under Punjab conditions and may be adopted in rotation with the rice-wheat system once every one or two years to maintain food security and long-term soil sustainability.

Key words: *Gobhi sarson*, *Kharif-rabi-zaid*, Pigeonpea, Productivity, Relay cropping.

INTRODUCTION

Pigeonpea (*Cajanus cajan* L.) is one of the most important pulse crops of the Indian subcontinent, well known for its multi-dimensional role in ensuring food, nutritional and ecological security. It is primarily grown as a *Kharif* crop and contributes significantly to soil fertility enhancement through biological nitrogen fixation, addition of organic matter through leaf fall and improvement of soil physical properties through deep root penetration (Das *et al.,* 2016). In India pigeonpea area is 4057.96 thousand hectare in 2025-26 with production and productivity of 3597.43 thousand tonnes and 887 kg ha^{-1} in 2025-26, respectively. In Punjab, it covers an area of about 0.40 thousand hectares with total production and productivity of 0.45 thousand tonnes and 1136 kg ha^{-1} in 2025-26, respectively (UPAg 2025-26). Being a long-duration legume crop, pigeonpea fits well in various intercropping and sequential cropping systems, especially in rainfed and irrigated ecosystems of the Indo-Gangetic Plains (IGP). However, its productivity in Punjab and adjoining regions remains low compared to its potential due to delayed sowing, poor crop stand establishment, sub-optimal management practices and severe weed infestation during early growth stages (Murali *et al.,* 2025). In Punjab, diversification of the dominant rice-wheat cropping system has become imperative to address challenges such as groundwater depletion, stubble burning and soil degradation (Bhatt *et al.,* 2021). The pigeonpea-*gobhi sarson*-summer moong cropping system offers a sustainable and remunerative alternative by improving soil health, reducing irrigation requirements and enhancing overall system productivity (Liu *et al.,* 2025). Pigeonpea being a leguminous crop, contributes to the soil nitrogen economy and improves soil structure, while *gobhi sarson* (*Brassica napus* L.) an oilseed crop, utilizes residual fertility and provides an additional source of income during the *Rabi* season. Hence, integrating *gobhi sarson* after timely sown pigeonpea can play a vital role in maintaining the productivity, profitability and sustainability of the region's cropping systems. *Gobhi Sarson* (*Brassica napus* L.) is a high-yielding, photo-insensitive and cold-tolerant oilseed

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crop that has shown excellent adaptability under the agro-climatic conditions of Punjab (Anonymous, 2024). It possesses a deep root system and robust vegetative growth that enable efficient utilization of soil nutrients and moisture. Integrating *gobhi sarson* after pigeonpea improves soil fertility through efficient nutrient recycling, while the legume-oilseed-pulse sequence enhances system productivity, resource use efficiency and farm profitability (Supriya *et al.,* 2020). Different planting methods of *gobhi sarson*, such as relay cropping, direct seeding and transplanting, have a pronounced effect on its establishment, growth and yield. Relay cropping, wherein *gobhi sarson* is sown into the standing pigeonpea crop 10-15 days before its harvest, ensures better use of residual soil moisture, a longer growing period and higher land-use efficiency (Tanveer *et al.,* 2017). This method also conserves soil moisture and reduces irrigation requirements. Direct seeding helps achieve uniform crop stand and timely establishment, whereas transplanting may give an initial growth advantage under late-sown conditions (Tariq *et al.,* 2022). The choice of planting method affects microclimatic parameters such as canopy temperature, photosynthetically active radiation (PAR) interception and soil moisture dynamics, thereby influencing overall system productivity and sustainability. Timely sowing and appropriate planting methods are crucial factors influencing the establishment, growth and yield of pigeonpea. The plant geometry and method of planting determine light interception, root growth, nutrient uptake and canopy structure which ultimately affect crop performance and system productivity. In the north-western Indo-Gangetic region, delayed sowing often exposes pigeonpea to terminal moisture stress, leading to shorter vegetative and reproductive phases (Flohr *et al.,* 2017). Thus, timely sowing of pigeonpea under suitable planting methods (ridge, furrow and flat bed) ensures uniform germination, better root development, improved drainage and enhanced aeration in heavy soils. Different planting methods modify the microenvironment around the rhizosphere and influence soil moisture, canopy temperature and weed dynamics (Jat *et al.,* 2021). Ridge and furrow planting has been reported to improve soil moisture conservation and minimize waterlogging compared to flat planting. Moreover, planting geometry affects photosynthetically active radiation (PAR) interception, canopy temperature and leaf area development, which influence crop growth and competitive ability against weeds. Among the biotic stresses, weeds are the most serious competitors of pigeonpea, particularly during the early stages of growth. Pigeonpea exhibits a slow initial growth rate and sparse canopy cover, which allows diverse weed flora to establish and compete vigorously for light, nutrients, moisture and space. To improve the productivity and weed management of pigeonpea-based systems, intercropping with short-duration legumes like cowpea has been found advantageous. Cowpea (*Vigna unguiculata* L.) is a fast-growing, multi-purpose legume that provides high-quality fodder, improves soil fertility through nitrogen fixation and suppresses weed growth through rapid canopy coverage. Its fodder contains about 23-32 per cent crude protein and 50 per cent digestible carbohydrates, along with essential minerals such as calcium and phosphorus (Abebe and Alemayehu, 2022). Intercropping cowpea with pigeonpea ensures better utilization of space, sunlight and nutrients, while simultaneously offering additional economic returns from fodder. The inclusion of cowpea also facilitates microclimatic regulation by reducing soil temperature fluctuations, conserving soil moisture and improving radiation interception (IPAR) within the pigeonpea canopy. Hence, the inclusion of cowpea intercrop in the pigeonpea-*gobhi sarson* sequence not only enhances system productivity but also strengthens the ecological sustainability of the system by improving soil fertility, increasing radiation use efficiency and reducing weed pressure. Although the pigeonpea-*gobhi sarson* cropping system holds great promise for diversification and resource conservation in Punjab, limited research exists on timely sown pigeonpea under different planting methods and their effect on intercropped cowpea and succeeding *gobhi sarson*, particularly with respect to microclimatic parameters (canopy temperature, PAR interception and leaf area index), weed dynamics, growth and yield attributes.

Despite the potential of the pigeonpea-*gobhi sarson*-summer moong cropping system, there is limited information on the performance of timely sown pigeonpea under different planting methods and their interaction with cowpea intercropping and relay cropping of *gobhi sarson* under Punjab conditions. Therefore, the present study was undertaken to address these gaps and assess the productivity and sustainability of pigeonpea-based diversified cropping systems.

MATERIALS AND METHODS

A field trial was conducted at Punjab Agricultural University, Ludhiana to evaluate the production potential of timely sown pigeonpea in Pigeonpea-*Gobhi Sarson* cropping system. The experiment was conducted during *Kharif* and *Rabi* seasons of 2023-24 and 2024-25 at the Students' Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana (30°56′N, 75°48′E and 247 meters above mean sea level). The site is located in the Trans-Gangetic Plains and is characterized by a subtropical, semi-arid climate with an average annual rainfall of about 700 mm, about 80-85 per cent of which occurs during June-September. Before establishing the experiment, composite soil samples were collected from 0-15 cm and 15-30 cm depth from the experimental field. The soil was sandy-loam in texture, slightly alkaline, non-saline, low in available nitrogen, medium in available phosphorus and adequate in available potassium. The experiment was laid out in randomized complete block design (RCBD) comprising

eight treatments with three replications (Table 1). The pigeonpea variety PAU 881, an early-maturing variety with an indeterminate growth habit was used. Pigeonpea was sown using a bed planter on top centre of freshly prepared beds at a spacing of 67.5 cm apart (37.5 cm bed top and 30 cm furrow). Seeds were inoculated with *Rhizobium* culture prior to sowing. Weed management consisted of a pre-emergence application of pendimethalin 30 EC @ 1.5 L ha^{-1} within two days of sowing, using 500 L litres water ha^{-1}, followed by manual hoeing at 6-7 weeks after sowing. Cowpea was intercropped with pigeonpea and sown manually using the *kera* method in furrows at the time of pigeonpea sowing. Cowpea was grown as a fodder crop and harvested at 35 days after sowing (DAS) and the fodder was used as feed for ruminants. Daily meteorological data, including temperature, relative humidity, rainfall, sunshine hours, wind speed and evaporation were recorded throughout the crop growth period. Microclimatic parameters including soil temperature was measured at 5 and 10 cm depths using calibrated soil thermometers at 08:30 and 14:00 hours on selected clear days to capture diurnal variation and effects of planting geometry and residue/ canopy cover. Canopy temperature (°C) of pigeonpea was measured periodically using an infrared thermometer between 12:00-14:00 hours under clear sky conditions. Canopy temperature was used as an indicator of crop water status and microclimate differences caused by planting method and intercrop shading. Leaf area index (LAI) was measured using a Sun Scan Canopy Analyzer (Model: Sun Scan type SS1, Manufactured by Delta-T Devices, Cambridge-England) between 12 pm to 2 pm. Intercepted photosynthetically active radiation (IPAR) was recorded using a line quantum sensor. The incoming and reflected radiations were measured at 1 m above crop canopy, while transmitted radiation was measured at the base of the crop canopy within the 400-700 nm wavelength range. 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}).

Data on various growth attributes such as plant height, number of branches plant, dry matter accumulation, leaf area index (LAI), leaf fall along with symbiotic traits including number of nodules $plant^{-1}$ and nodules dry weight $plant^{-1}$ were recorded at 60 and 90 days after sowing. For plant height, 10 plants were selected randomly, tagged and measured in cm. While, dry matter accumulation was determined by harvesting 0.5 m row length from two locations in the penultimate rows, followed by oven drying at 70°C for 72 hours. 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 number of nodules $plant^{-1}$ and then oven dried to obtain their dry weight $plant^{-1}$. 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, stalk and biological yields were recorded and expressed on a per hectare basis. 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}. In Cowpea fodder yields (green and dry) were recorded on a plot basis and expressed as g m^{-2}. All experimental data were subjected to analysis of variance (ANOVA) appropriate for RCBD. Treatment means were compared using the critical difference at 5% probability level using SAS statistical software (SAS Institute Inc. 2014).

RESULTS AND DISCUSSION

Growth parameters

Growth parameters (Table 2) *viz*. plant height, dry matter accumulation, leaf area index (LAI), leaf fall were considerably in pigeonpea-*Gobhi Sarson*-Summer Moong

Table 1: Treatment details.

Treatments	Cropping systems
T_1	Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong
T_2	Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong
T_3	Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong
T_4	Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong
T_5	Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong
T_6	Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong
T_7	Pigeonpea (PAU 881) - Wheat
T_8	Pigeonpea (AL 882) - Wheat

Table 2: Growth parameters of timely sown pigeonpea in pigeonpea-*Gobhi sarson*-summer moong cropping system during *kharif* season.

Treatments	Growth parameters											
	Plant height (cm)			Dry matter accumulation (g m^{-2})			Leaf area index			Leaf fall (g m^{-2})		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
T_1: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	138.3	139.2	138.75	290.3	300.7	295.50	7.07	7.13	7.10	234.2	281.4	257.80
T_2: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	133.6	134.7	134.15	284.1	295.3	289.70	7.03	7.11	7.07	214.7	257.2	235.95
T_3: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	131.5	132.1	131.80	280.7	290.4	285.55	7.01	7.09	7.05	206.4	250.6	228.5
T_4: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	128.3	129.9	129.10	315.2	340.2	327.70	7.83	7.94	7.88	250.1	300.0	275.05
T_5: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	125.7	126.3	126.00	311.4	334.7	323.05	7.70	7.79	7.74	219.6	263.4	241.50
T_6: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	125.3	126.8	126.05	300.3	320.8	310.55	7.43	7.57	7.50	209.8	251.7	230.75
T_7: Pigeonpea (PAU 881) - Wheat	126.7	127.4	127.05	274.7	295.1	284.90	6.36	6.69	6.52	173.4	186.2	179.8
T_8: Pigeonpea (AL 882) - Wheat	120.1	120.6	120.35	289.9	313.7	301.8	7.10	7.30	7.20	189.9	200.5	195.2
CD (p=0.05)	8.89	9.24	7.03	24.37	25.96	28.21	0.66	0.63	0.57	25.31	25.96	27.23

cropping system. Timely sown pigeonpea grown in association with cowpea followed by *gobhi sarson* and summer moong recorded highest growth as compared to the pigeonpea-wheat system. Among different treatments, pigeonpea (PAU 881) + cowpea (F) - *gobhi sarson* (relay cropping) - summer moong (T_4) recorded the highest plant height (138.3 and 139.2 cm whereas, pigeonpea (AL 882) + cowpea (F) - *gobhi sarson* (relay cropping) - summer moong (T_4) recorded significantly higher dry matter accumulation (315.2 g m^{-2} and 340.2 g m^{-2}), LAI (7.83 and 7.94) and leaf fall (250.1 g m^{-2} and 300.0 g m^{-2}) during 2023 and 2024, respectively. The enhanced growth under relay cropping might be attributed to better utilization of growth resources, greater canopy coverage and improved soil fertility due to biological nitrogen fixation by legumes and continuous nutrient recycling through residue decomposition. The inclusion of cowpea as an intercrop contributed to improved soil organic matter and nitrogen availability, which in turn enhanced vegetative growth and photosynthetic activity of pigeonpea. Similarly, relay cropping with *gobhi sarson* ensured efficient resource use and minimal competition, resulting in better light interception and moisture utilization. The higher LAI under AL 882 based systems might be due to prolonged leaf retention and greater leaf expansion, leading to higher interception of photosynthetically active radiation and consequently higher dry matter accumulation. These findings are in close agreement with Kumar *et al.* (2018) and Gawdiya *et al.* (2022), who observed that inclusion of legumes and residue retention enhanced growth and productivity in pigeonpea-based systems.

Table 3: Symbiotic traits of timely sown pigeonpea under different planting methods of *gobhi sarson* in pigeonpea-*gobhi sarson* cropping system during *kharif* season.

Treatments	Nodules plant^{-1} (No.)			Dry weight of nodules (mg plant^{-1})		
	2023	2024	Pooled	2023	2024	Pooled
T_1: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	21.83	22.17	22.00	41.45	42.34	41.89
T_2: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	21.76	22.14	21.95	41.34	42.21	41.77
T_3: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	21.62	22.08	21.85	41.22	42.12	41.67
T_4: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	22.56	23.74	23.15	42.48	43.20	42.84
T_5: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	22.45	23.65	23.05	42.37	43.18	42.77
T_6: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	22.36	23.53	22.94	42.22	43.12	42.67
T_7: Pigeonpea (PAU 881) -Wheat	20.54	21.59	21.06	40.16	41.06	40.61
T_8: Pigeonpea (AL 882) - Wheat	21.66	22.36	22.01	41.08	42.03	41.55
CD (p=0.05)	NS*	NS	NS	NS	NS	NS

*NS- Non significant at p=0.05.

Symbiotic traits

Symbiotic traits such as number of nodules plant^{-1} and dry weight of nodules plant^{-1} (Table 3) were also influenced by different planting methods of gobhi sarson in Pigeonpea-*Gobhi Sarson* cropping system. Although differences among treatments were statistically non-significant, pigeonpea grown under T_4 [AL 882 + cowpea - *gobhi sarson* (relay cropping) - summer moong] recorded the highest number of nodules (25.43 and 26.32 nodules plant^{-1}) and nodule dry weight (44.21 and 44.30 mg plant^{-1}) during *Kharif* 2023 and 2024, respectively. The enhanced nodulation under diversified systems might be attributed to improved rhizospheric conditions created by legume inclusion and residue recycling, which enhanced microbial activity and rhizobial population. Cowpea being a promiscuous legume, also supported better nitrogen fixation in the system through cross-rhizobial associations. Similar findings were reported by (Binacchi *et al.,* 2022; Ndungu *et al.,* 2018), who highlighted the positive impact of legume integration on root nodulation and nodule biomass in pigeonpea-based systems.

Yield attributes

Various yield attributes of pigeonpea crop such as number of pods plant^{-1}, pod length, number of seeds pod^{-1} and

100-seed weight (Table 4a and Table 4b) were also influenced by timely sown pigeonpea in pigeonpea-*gobhi sarson*-summer moong cropping system. The maximum number of pods plant^{-1} was recorded under T_4 (140.80 and 145.23), which was statistically at par with T_5 (139.70 and 142.41) and T_6 (137.49 and 140.47). The highest pod length (4.75 and 5.16 cm), seeds pod^{-1} (4.16 and 4.24) and 100-seed weight (7.18 and 7.33 g) were also recorded under T_4 during 2023 and 2024, respectively. The improvement in yield attributes might be attributed to increased photosynthetic efficiency, better source-sink relationship and efficient translocation of photosynthates towards reproductive organs. These findings are in agreement with Kumar *et al.* (2022) and Kumar *et al.* (2023).

Crop yield

Crop yield *viz.* seed yield, stalk yield and biological yield (Table 5a and Table 5b) were significantly higher in pigeonpea (AL 882) + cowpea (F) - *gobhi sarson* (relay cropping) - summer moong (T_4). There was 12.44 and 10.81 per cent increase in seed yield, 17.34 and 15.35 per cent higher stalk yield, while the biological yield increased by 16.22 and 14.33 per cent under T_4 over pigeonpea (PAU 881) - wheat (T_7) during *Kharif* season of the year 2023 and 2024, respectively. The enhanced yield under T_4 could be ascribed to better light interception, efficient utilization of resources and improved crop growth under relay cropping with *gobhi sarson*. The higher yield performance may be ascribed to optimum nutrient availability at critical growth stages, improved soil physical and biological conditions and effective utilization of light, water and nutrients. Continuous organic matter addition through crop residues and leaf fall further improved soil health and supported sustained productivity. Similar findings were reported by Blanco-Canqui and Lal (2009); Kaschuk *et al.* (2010); Chauhan *et al.* (2007).

Growth, yield attributes and yield of cowpea (F)

Growth parameters of cowpea (Table 6) such as fresh weight and dry weight were also influenced by timely sown pigeonpea in pigeonpea-*gobhi Sarson*-Summer Moong cropping system. Although the variations were statistically non-significant, numerically higher values were observed under pigeonpea (AL 882) + cowpea (F) - *gobhi sarson* (relay cropping) - summer moong (T_4). Enhanced growth under these systems might be attributed to favourable microclimatic conditions, improved light interception and enhanced soil fertility resulting from legume integration and biological nitrogen fixation by pigeonpea. These results are consistent with the findings of Phiri *et al*. (2024) and Dangi *et al*. (2020), who reported that intercropping legumes under diversified systems promotes complementary resource use and better vegetative development. Yield parameters of cowpea fodder, including dry weight (198.4 and 200.8 g m^{-2}), were also higher under AL 882 based relay cropping (T_4) compared to other treatments. The improved performance under these

Table 4a: Pods plant^{-1} and pod length of timely sown pigeonpea in pigeonpea-*gobhi sarson*-summer moong cropping system during *kharif* season.

Treatments	Pods plant^{-1} (No.)			Pod length (cm)		
	2023	2024	Pooled	2023	2024	Pooled
T_1: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	125.13	127.02	126.07	4.52	4.95	4.73
T_2: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	123.17	125.10	124.13	4.46	4.61	4.53
T_3: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	119.04	121.15	120.09	4.38	4.56	4.47
T_4: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	140.80	145.23	143.01	4.75	5.16	4.95
T_5: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	139.70	142.41	141.05	4.69	4.97	4.83
T_6: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	137.49	140.47	138.98	4.54	4.86	4.70
T_7: Pigeonpea (PAU 881) - Wheat	118.35	120.59	119.47	4.26	4.37	4.31
T_8: Pigeonpea (AL 882) - Wheat	134.24	137.60	135.92	4.30	4.79	4.54
CD (p=0.05)	13.02	14.06	6.45	NS*	NS	NS

*NS- Non significant at p=0.05.

Table 4b: Seeds pod^{-1} and 100-seed weight of timely sown pigeonpea in pigeonpea-*Gobhi sarson*-summer moong cropping system during *kharif* season.

Treatments	Seeds pod^{-1} (No.)			100-seed weight (g)		
	2023	2024	Pooled	2023	2024	Pooled
T_1: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	3.73	3.81	3.77	6.86	6.97	6.91
T_2: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	3.62	3.72	3.67	6.72	6.88	6.80
T_3: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	3.45	3.53	3.49	6.65	6.80	6.72
T_4: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	4.16	4.24	4.20	7.18	7.33	7.25
T_5: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi Sarson* (DS) - Summer moong	4.11	4.19	4.15	7.15	7.31	7.23
T_6: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	4.07	4.15	4.11	7.01	7.14	7.07
T_7: Pigeonpea (PAU 881) - Wheat	2.98	3.06	3.02	5.45	5.61	5.53
T_8: Pigeonpea (AL 882) - Wheat	3.52	4.11	3.81	6.82	6.89	6.85
CD (p=0.05)	NS*	NS	NS	NS	NS	NS

*NS- Non significant at p=0.05.

Table 5a: Seed yield and stalk yield of timely sown pigeonpea in pigeonpea-*Gobhi garson*-gummer moong cropping system during *kharif* season.

Treatments	Seed yield (kg ha^{-1})			Stalk yield (kg ha^{-1})		
	2023	2024	Pooled	2023	2024	Pooled
T_1: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	1254	1327	1291	4413	4814	4614
T_2: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	1222	1316	1269	4206	4599	4403
T_3: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	1211	1309	1260	3997	4417	4207
T_4: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	1330	1416	1373	4637	4999	4818
T_5: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	1325	1407	1366	4308	4704	4506
T_6: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	1314	1405	1360	4131	4509	4320
T_7: Pigeonpea (PAU 881) -Wheat	1183	1278	1231	3951	4333	4142
T_8: Pigeonpea (AL 882) - Wheat	1238	1333	1286	4095	4387	4241
CD (p=0.05)	112	113	85	NS*	NS	NS

*NS- Non significant at p=0.05.

Table 5b: Biological yield and harvest index of timely sown pigeonpea in pigeonpea-*Gobhi sarson*-summer moong cropping system during *kharif* season.

Treatments	Biological yield (kg ha^{-1})			Harvest index (%)		
	2023	2024	Pooled	2023	2024	Pooled
T_1: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	5667	6141	5904	22.12	21.60	21.86
T_2: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	5482	5915	5699	22.30	22.24	22.27
T_3: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	5208	5726	5467	23.25	22.86	23.05
T_4: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	5967	6415	6191	22.28	22.07	22.17
T_5: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	5633	6111	5872	23.52	23.02	23.27
T_6: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	5445	5914	5680	24.13	23.75	23.94
T_7: Pigeonpea (PAU 881) - Wheat	5134	5611	5373	23.04	22.77	22.90
T_8: Pigeonpea (AL 882) - Wheat	5333	5720	5527	23.21	23.30	23.25
CD (p=0.05)	NS*	NS	NS	NS	NS	NS

*NS- Non significant at p=0.05.

Table 6: Fresh and dry weight of cowpea (fodder) in pigeonpea+cowpea intercropping system during *kharif* season.

Treatments	Fresh weight (g m^{-2})			Dry weight (g m^{-2})		
	2023	2024	Pooled	2023	2024	Pooled
T_1: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	893.10	902.56	897.83	196.48	198.59	197.53
T_2: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	893.06	902.48	897.77	196.45	198.51	197.48
T_3: Pigeonpea (PAU 881) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	893.01	902.13	897.57	196.42	198.42	197.42
T_4: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (Relay cropping) - Summer moong	895.12	904.23	899.67	198.54	200.41	199.47
T_5: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (DS) - Summer moong	895.09	904.16	899.62	198.43	200.32	199.37
T_6: Pigeonpea (AL 882) + Cowpea (F) - *Gobhi sarson* (T) - Summer moong	895.02	904.12	899.57	198.34	200.23	199.28
CD (p=0.05)	NS*	NS	NS	NS	NS	NS

*NS- Non significant at p=0.05.

systems could be ascribed to better canopy compatibility, efficient utilization of available nutrients and moisture and reduced interspecific competition during early growth stages. Overall, the inclusion of cowpea in pigeonpea-based diversified systems proved beneficial not only for soil fertility enhancement but also for improving system productivity and fodder quality. The integration of legumes like cowpea and pigeonpea in relay and intercropping sequences ensured complementary resource use, sustainable yield advantage and improved ecosystem functioning.

Growth, yield attributes and yield of *Gobhi sarson*

Growth and yield of *gobhi sarson* were significantly influenced by pigeonpea-based diversified cropping systems. *Gobhi sarson* grown under pigeonpea (AL 882) + cowpea (F) - *gobhi sarson* (relay cropping) - summer moong (T_4) recorded the highest plant height (100.5 and 101.2 cm), dry matter accumulation (449.5 and 456.2 g m^{-2}) and leaf area index (2.62 and 2.67) during *Rabi* 2023-24 and 2024-25, respectively. Yield attributes such as number of siliquae $plant^{-1}$ (285.9 and 291.8) and seeds $siliquae^{-1}$ (22.8 and 23.4) were also superior under T_4, which resulted in significantly higher seed yield (23.97 and 24.54 q ha^{-1}). The enhanced performance of *gobhi sarson* under relay cropping may be attributed to better utilization of residual soil moisture, improved availability of nutrients due to preceding legume crops, enhanced soil organic matter and favourable soil physical and biological conditions. Improved root growth and efficient partitioning of assimilates towards reproductive structures under diversified systems further contributed to higher productivity, supporting the role of pigeonpea-based relay cropping in improving system sustainability and soil fertility. These observations are supported by the findings of Pandey *et al*. (2021) and Singh *et al*. (2019).

Growth, yield attributes and yield of summer moong

Growth and yield of summer moong were significantly influenced by pigeonpea-based diversified cropping systems. Summer moong grown under pigeonpea (AL 882) + cowpea (F) - *gobhi sarson* (relay cropping) - summer moong (T4) recorded higher plant height at harvest 51.8 cm during *Zaid* 2024 and 51.9 cm during *Zaid* 2025 and leaf area index at 60 DAS (4.4 and 4.5) during *Zaid* 2024 and 2025, respectively. This resulted in significantly higher seed yield 10.81 q ha^{-1} during 2024 and 11.85 q ha^{-1} during 2025 and stover yield (28.95 and 30.68 q ha^{-1}). The superior growth and yield of summer moong under pigeonpea-based relay cropping systems can be attributed to enhanced residual soil fertility, particularly nitrogen contribution from preceding legume crops. Improved soil structure, higher organic matter content and better soil moisture retention under legume-based rotations created a favourable rhizosphere, resulting in improved crop establishment, higher leaf area index and better photosynthetic efficiency. Enhanced nutrient uptake, efficient assimilate partitioning and improved root growth under relay cropping led to superior yield attributes and higher productivity of summer moong, highlighting the benefit of pigeonpea-based diversified cropping systems for sustainable pulse production. Almost similar findings were reported by Sharma *et al*. (2023).

CONCLUSION

This study highlights the importance of timely sown pigeonpea in pigeonpea-*gobhi sarson*-summer moong cropping system for improving productivity and sustainability. It is concluded that timely sown pigeonpea (AL 882) with cowpea (F) intercropping, followed by *gobhi sarson* (relay cropping) and summer moong, exhibited the highest growth, yield attributes, owing to efficient utilization of available resources and enhanced nutrient uptake. The inclusion of cowpea improved soil fertility through biological nitrogen fixation and residue contribution, while relay sowing of *gobhi sarson* efficiently utilized residual soil moisture and nutrients, thereby enhancing overall system efficiency and sustainability. Therefore, adoption of timely sown pigeonpea-based cropping systems offers a promising and sustainable alternative to conventional rotations, improving productivity, profitability and resource-use efficiency in the Trans-Gangetic Plains of India.

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Disclaimers

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Conflict of interest

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