PLANT SCIENCE TODAY
Vol 13(sp9): 1–15
https://doi.org/10.14719/pst.16142

eISSN 2348-1900
OPEN ACCESS

Research Article | Agriculture
2026, Volume 13, Issue sp9, pp. 1-15

Quality, land-use efficiency and economics of high-density cotton in paired-row pigeonpea intercropping under different nitrogen and growth regulator management

Durgam Venkatesh[1*], C Sudha Rani[2], C Sudhakar[3], T Ram Prakash[4] & K Supriya[5]

[1]Department of Agronomy, College of Agriculture, Professor Jayashankar Telangana Agricultural University (PJTAU), Rajendranagar, Hyderabad 500 030, Telangana, India

[2]Department of Agronomy, Agricultural Research Station, Professor Jayashankar Telangana Agricultural University (PJTAU), Tandur, Vikarabad 501 141, Telangana, India

[3]Department of Agronomy, Agricultural College, Professor Jayashankar Telangana Agricultural University (PJTAU), Kodangal, Vikarabad 501 141, Telangana, India

[4]Department of Soil Science and Agricultural chemistry, Regional Agricultural Research Station (RARS), Professor Jayashankar Telangana Agricultural University (PJTAU), Palem, Nagarkurnool 509 215, Telangana, India

[5]Department of Statistics and Mathematics, College of Agriculture, Professor Jayashankar Telangana Agricultural University (PJTAU), Rajendranagar, Hyderabad 500 030, Telangana, India

***Correspondence:** durgamvenkateshswaero@gmail.com

Abstract

The experiment was carried out to examine the performance of paired-row pigeonpea in a high-density cotton intercropping system and to evaluate the quality and economics of high-density cotton grown with paired-row pigeonpea. The space between the two paired rows of pigeonpea was effectively used to grow high-density cotton. The trial was conducted at the Agricultural Research Station (ARS) Tandur, Vikarabad during kharif 2023–24 and 2024–25 and was laid out in a split-plot design with 3 replications. The main plots comprised paired rows of pigeonpea between high-density cotton spacing, while the subplots consisted of 6 treatments with varying levels of nitrogen and growth regulators. Among the main plots, the high-density cotton spacing of 60 × 15 cm (M_1) significantly recorded the highest mean maximum gross returns (243347), net returns and benefit–cost (B : C) ratio (2.68), as well as land equivalent ratio (LER) of (1.36). However, the superior fibre quality parameters were observed with the higher density cotton spacing of 100 × 15 cm (M_3) during 2023–24, 2024–25 and in the mean results. Among the subplots, the highest mean gross returns (243589), net returns (155015), B : C ratio (2.74) and LER of (1.38) were recorded and the maximum quality parameters were obtained with the application of 125 % recommended dose of nitrogen (RDN) + mepiquat chloride 50 ppm at the square formation and flowering stage (S_3). This treatment was statistically comparable to the application of 100 % RDN + mepiquat chloride 50 ppm at the square formation and flowering stage (S_2), which produced mean gross returns (213855), net returns (136907), B : C ratio (2.55) and LER of (1.31). The application of 125 % RDN + cycocel 60 ppm at the square formation and flowering stage (S_6) also showed comparable performance, with mean gross returns (227144), net returns (138970), B : C ratio (2.57) and LER of 1.28 across 2023–24, 2024–25 and the mean data.

Keywords: cycocel; growth regulators; high-density cotton; mepiquat chloride; nitrogen management; paired-row intercropping

Received: 17 June 2026. **Accepted:** 05 November 2026. **Available online:** Version 1.0: 23 November 2026.

Cite this article: Durgam V, Sudha RC, Sudhakar C, Ram PT, Supriya K. Quality, land-use efficiency and economics of high-density cotton in paired-row pigeonpea intercropping under different nitrogen and growth regulator management. Plant Science Today. 2026; 13(sp9): 1-15. https://doi.org/10.14719/pst.16142

Introduction

Pigeonpea (*Cajanus cajan* L.) ranks as India's second-most important pulse after chickpea and is a key grain legume of the kharif (monsoon) season. It is largely cultivated under rainfed conditions across the country. Currently pigeonpea occupies about 50.02 lakh hectares in India, producing around 4.34 million tonnes with an average yield of 877 kg ha^{-1} (1).

In the paired-row pigeonpea-cotton intercropping layout, the gap between the two pigeonpea rows is used to plant cotton at high-density, making efficient use of field space. Paired-row planting system allows for better light interception by the crop and resource sharing for harvesting better yields (2). Pigeonpea also adapts well to intercropping with several crops such as cotton, sorghum, pearl millet, greengram, black gram, maize, soybean and groundnut helping to boost overall production, improve resource-use efficiency and support soil fertility. Pigeonpea improves soil quality, lowers climatic risks and the likelihood of crop failure, strengthens biodiversity and promotes more effective

use of resources and land area (3, 4). Pigeonpea is appropriate for intercropping with various crops such as cotton, sorghum, pearl millet, greengram, black gram, maize, soybean and groundnut to boost production, enhance resource-use efficiency and preserve soil fertility. Paired-row pigeonpea-based intercropping systems with high-density cotton constitute a deliberately designed cropping arrangement that combines the Compatible growth characteristics of pigeonpea and cotton to maximise land productivity and resource-use efficiency was stated in previous studies (5). Pigeonpea was planted in paired-rows with sufficient spacing within each pair, while the larger inter-pair gaps were used to accommodate closely spaced cotton rows. This setup enables the simultaneous cultivation of two crops on the same land, capitalising on pigeonpea's vertical structure and deep-rooting capacity together with the rapid canopy development and economic yield potential of high-density cotton (6). Adequate nitrogen supports crop growth and yield formation, excessive nitrogen may favour prolonged vegetative growth and reduce the efficiency of assimilate partitioning towards reproductive structures. The use of plant growth regulators such as mepiquat chloride can help regulate excessive vegetative growth and improve canopy architecture in high-density cotton. Mepiquat chloride is particularly relevant under high-density planting system (HDPS) because a compact and well-regulated canopy can improve light distribution within the crop, reduce excessive vegetative competition and favour reproductive growth. The combined consideration of nitrogen supply and mepiquat chloride application may therefore provide a more effective approach to managing cotton growth under high plant density. Therefore, the present study was undertaken to evaluate the execution of high-density cotton planted at different spacings within a paired-row pigeonpea intercropping system and to assess the effects of nitrogen levels and growth-regulator management on fibre quality, land-use efficiency and economic returns over two kharif seasons, with the aim of identifying a suitable planting and crop-management combination for improving the overall productivity and economic execution of the system under the prevailing experimental conditions. The execution of different cotton planting geometries in paired-row pigeonpea intercropping and to assess the effects of nitrogen management and plant growth regulators on cotton fibre quality, land-use efficiency and economic returns, thereby identifying an agronomically and economically suitable management combination for the experimental conditions.

Materials and Methods

The trial took place at the Agricultural Research Station (ARS), Tandur, Vikarabad, Telangana. The research farm is located at 350 m above mean sea level (17°22′ N, 77°58′ E) within Telangana's Southern agro-climatic zone. Using Troll's climatic classification, the site is characterised as semi-arid tropics (SAT).

Crop establishment and treatment details

The experimental field consisted of clay loam soil with a slightly alkaline reaction (pH 7.91), medium organic carbon, low available nitrogen (208.6 kg ha^{-1}), high available phosphorus (21.6 kg ha^{-1}) and medium available potassium (301.4 kg ha^{-1}). A split-plot design with 3 replications and 18 treatments was used during kharif 2023–24 and 2024–25. The gross plot size was (11.70 × 6 m) and net plot size was (7.9 × 4 m) equal for all plots. The Main-plot treatments comprised paired-row pigeonpea intercropped with high-density cotton at three planting geometries: M_1- cotton at 60 × 15 cm (approximately 111111 plants ha^{-1}); M_2-cotton at 75 × 20 cm (approximately 66666 plants ha^{-1}); and M_3-cotton at 100 × 15 cm (approximately 66666 plants ha^{-1}). Subplot treatments involved combinations of growth regulators and nitrogen management: S_1- 100 % recommended dose of nitrogen (RDN) plus mepiquat chloride 50 ppm at square initiation, peak square formation and flowering; S_2- 100 % RDN + mepiquat chloride 50 ppm at square formation and flowering; S_3- 125 % RDN + mepiquat chloride 50 ppm at square formation and flowering; S_4- 100 % RDN + chlormequat chloride (cycocel) 60 ppm at square initiation, peak square formation and flowering; S_5- 100 % RDN + cycocel 60 ppm at square formation and flowering; and S_6 - 125 % RDN + cycocel 60 ppm at square formation and flowering.

Cotton variety ADB-39 and pigeonpea variety TDRG 59 were sown by dibbling. Pigeonpea was planted in paired-rows with 45 cm spacing within a pair and a 3.0 m gap between pairs. Within this 3.0 m inter-pair space, high-density cotton was planted according to the three spacing treatments: M_1 accommodated five cotton rows, M_2 accommodated four cotton rows and M_3 accommodated three cotton rows; these arrangements were maintained in over experimental years. The recommended dose of fertiliser (RDF) for pigeonpea (20 kg nitrogen and 50 kg phoshphorus pentoxide (P_2O_5) ha^{-1}) was applied as basal urea and single superphosphate across all pigeonpea plots according to treatment specifications. Weed control included a pre-emergence application of pendimethalin at 0.75 kg a.i. ha^{-1} on the second day after sowing, followed by manual weeding at 40 and 70 days after sowing (DAS) in over kharif seasons (2023–24 and 2024–25). Sucking pests were managed initially with fipronil 5 % suspension concentrate (SC) at 4 mL L^{-1}, followed at later stages by imidacloprid at 0.45 mL L^{-1}. To control bollworms (*Pectinophora gossypiella*), Chlorantraniliprole (10 %) + Lambda-cyhalothrin 5 % capsule suspension–suspension concentrate (ZC) at 0.5 mL L^{-1} was applied during boll development in 2023–24; in 2024–25, emamectin benzoate 5 % soluble granules (SG) at 0.5 g L^{-1} was sprayed at 105 and 120 DAS. Pigeonpea received the RDF of 20 kg nitrogen and 50 kg P_2O_5 ha^{-1}. Urea and single superphosphate were used as fertiliser sources and applied as basal fertiliser. The same fertiliser schedule was followed across the pigeonpea component of the intercropping treatments. For cotton, the recommended fertiliser dose was 120 kg nitrogen, 60 kg

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

P_2O_5 and 60 kg potassium oxide (K_2O) ha^{-1}. Urea, diammonium phosphate and muriate of potash were used as fertiliser sources. The nitrogen treatments consisted of 100 % RDN (120 kg N ha^{-1}) and 125 % RDN (150 kg N ha^{-1}), as specified in the subplot treatments. Nitrogen and potassium were applied in four equal splits at 20, 40, 60 and 80 DAS by band placement.

The cost of cultivation was computed for each treatment by considering the expenditure incurred on field preparation, seed, fertilisers, plant protection measures, labour, machinery operations and application of plant growth regulators, as applicable to the respective treatment. Treatment-specific input quantities were used for calculating the corresponding input costs. Gross returns were computed based on the yield of cotton and pigeonpea and their respective prevailing prices during each experimental year. The same pricing basis was applied consistently within each year for comparison among treatments. Net returns were estimated by deducting the cost of cultivation from gross returns, whereas the benefit ratio was obtained as the ratio of gross returns to the cost of cultivation.

The prices used for cotton are (₹7121 $quintal^{-1}$) for 2023–24 and (₹7521 $quintal^{-1}$) for 2024–25. For Pigeonpea are (₹7000 $quintal^{-1}$) for 2023–24 and (₹7550 $quintal^{-1}$) for 2024–25. Thus, the economic analysis accounted for year-specific differences in crop prices and treatment-specific differences in production costs.

Observations noted

Fibre quality was evaluated with a High-Volume Instrument (HVI) and an advanced fibre information system (AFIS) under controlled conditions of 21 ± 1 °C and 65 ± 2 % relative humidity. The HVI was used to determine fibre length, strength, micronaire, uniformity index, elongation, colour and trash content, while AFIS was employed for detailed single-fibre analysis including short fibre content, nep count, fineness and maturity parameters. The observations were noted from replicated samples and averaged for statistical analysis.

Ginning percentage

The lint obtained from each plant was weighed and the ginning was worked out by the formula given below (7).

$$\text{Ginning percentage (GP, \%)} = \frac{\text{Lint yield (Fibre)}}{\text{Seed cotton yield (Fibre + Seeds)}} \times 100$$

Lint index

Lint index was computed using GP and seed index data by using the following formula (8).

$$\text{Lint index} = \frac{\text{Seed index x Ginning percentage (GP)}}{100 - \text{GP}}$$

Fibre fineness

Fibre fineness, commonly expressed as micronaire, represents the resistance of a cotton sample to airflow and is an indirect measure of fibre weight per unit length. Traditionally micronaire denotes fineness and is obtained by measuring the airflow through a defined mass of compressed lint. For the present study, a 50 g sample was placed in the instrument's cylinder and air at a specified pressure was forced through the material; the resulting airflow reading is converted to micronaire units, with lower values indicating finer fibres.

Elongation (%)

The stelometer, which measures fibre bundle force and degree of elongation, is a conventional reference method for measuring fibre tensile properties. The stelometer can measure over the breaking strength and the breaking elongation.

Bundle strength

It is the force to break off a fibre of unit linear density. Fibre strength was determined by using the HVI and expressed in grams per tex.

Gross returns (₹ ha^{-1})

Gross returns were computed by using minimum support price (MSP) during kharif, 2023–24 and 2024–25 and by multiplying them with respective seed yield and expressed in ₹ ha^{-1}

Net returns (₹ ha^{-1})

Net returns were computed as gross returns minus total cultivation costs and are stated in ₹ ha^{-1}.

Benefit–cost ratio

The benefit–cost (B : C) ratio was computed by dividing the gross returns by the total cultivation cost.

$$\text{Benefit : cost ratio} = \frac{\text{Gross returns (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

Land equivalent ratio

Land equivalent ratio (LER) was used to quantify the yield advantage of the intercropping system over sole cropping, indicating the relative efficiency of resource use by the intercrop compared to monocrops:

$$LER = LER_a + LER_b = \frac{Yab}{Yaa} + \frac{Yba}{Ybb}$$

Yab: Yield of crop 'a' in intercropping with 'b'

Yaa: Yield of crop 'a' in pure stand

Yba: Yield of crop 'b' in intercropping with 'a'

Ybb: Yield of crop 'b' in pure stand

LER > 1: Intercropping is advantageous (greater total yield per area than sole cropping)

LER = 1: No advantage

LER < 1: Disadvantage in intercropping

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

Statistical analysis

All data were subjected to analysis of variance (ANOVA) following the split-plot design procedure described by previous researchers (9). The statistical model partitioned total variation into replication, main-plot treatment (M), main-plot error (replication × M interaction), sub-plot treatment (S), M × S interaction and sub-plot error. The significance of each treatment effect and their interaction (M × S and S × M) was tested using the *F*-statistic at the 5 % level of probability (p = 0.05). Where the *F*-test indicated a significant treatment effect, means were separated using the critical difference (CD), equivalent to the least significant difference (LSD) at p = 0.05, computed separately for main-plot comparisons (using the main-plot error mean square) and sub-plot and interaction comparisons (using the sub-plot error mean square). Treatment effects that did not attain significance at p = 0.05 were denoted as non-significant (NS) in all tables. Standard error of the mean (SE m±) was stated alongside the CD for each source of variation to indicate the precision of treatment estimates. The analysis was performed using IBM SPSS Statistics (Version 32.0.x). The assumptions underlying ANOVA, including normality of residuals and homogeneity of variance, were assessed using the appropriate diagnostic procedures available in SPSS. Where necessary, the data were examined for departures from these assumptions before interpretation of the ANOVA results.

The significance of treatment effects and the main-plot × subplot interaction was tested using the *F*-test at the 5 % probability level ($p \leq 0.05$). When a treatment effect was statistically significant, means were compared using the appropriate CD at the 5 % probability level, separately for main-plot treatments, subplot treatments and their interaction. Treatment effects with $p > 0.05$ were considered statistically non-significant (NS) and numerical differences among such treatments were not interpreted as meaningful treatment effects. Similarly, when the main-plot × subplot interaction was non-significant, the main effects were interpreted independently rather than attributing treatment-specific differences to the interaction. The results are therefore presented and interpreted based on statistical significance rather than numerical differences alone.

Results and Discussion

Available nitrogen (kg ha^{-1})

Substantially higher post-harvest available nitrogen levels (228, 221 and 224 kg ha^{-1}) were noted under a plant spacing of M_3 during 2023–24, 2024–25 and for the pooled results, respectively (Table 1). These values were statistically comparable to those noted for M_2 in over years and in the mean data. Conversely, the lowest post-harvest available nitrogen levels (247, 242 and 244 kg ha^{-1}) were observed with the narrow plant spacing of M_1 during over years and in the mean analysis. Among the subplot treatments, higher post-harvest available nitrogen (246, 242 and 245 kg ha^{-1}) was noted with the application of S_3. This was statistically comparable to S_2 and to the application of S_6 applied at the square formation and flowering stage during over years and in the mean data.

Available phosphorus (kg ha^{-1})

Higher post-harvest available phosphorus (Table 1) (32.5, 30.1 and 31.6 kg ha^{-1}) was noted with plant spacing of M_3 during 2023–24, 2024–25 and in the mean data, respectively. This was statistically comparable to M_2 for the same years and in the mean data. The lowest available phosphorus (37.7, 35.1 and 36.4 kg ha^{-1}) was registered with the narrow plant spacing of M_1 during over years and in the mean results. Among the subplot treatments, the highest post-harvest available phosphorus (38.4, 35.7 and 37.1) was obtained with the application of S_3. This was statistically comparable to S_2 and to S_6 during over years and in the mean data.

Available potassium (kg ha^{-1})

Among the main plots, the M_3 resulted in significantly higher post-harvest available potassium status in the soil (259, 249 and 254 kg ha^{-1}) during 2023–24, 2024–25 and the respective mean results (Table 1.) In contrast, the M_1 led to low available potassium (297, 291 and 294 kg ha^{-1}) during over years and in the mean results. The highest post-harvest available potassium (301, 293 and 297 kg ha^{-1}) was recorded with the application of S_3. However, this was at par with the application of S_2 and with S_6 across over years and in the mean data. The lowest available potassium (258, 247 and 252 kg ha^{-1}) was observed with S_4. Post-harvest soil nutrient status provides an indication of the residual nutrient availability following crop growth and reflects the effects of different nitrogen and growth-regulator management practices on soil fertility. Since nutrient availability influences crop growth, assimilate production and reproductive development, these changes may also contribute to variations in fibre development and quality.

Quality parameters

Ginning percentage

Ginning percentage data are shown in Table 2. Ginning percent was not significantly affected by the paired-row pigeonpea in main-plot treatments, the sub-plot treatments involving growth regulators and nitrogen management. Numerically, the highest GPs (37.7, 36.6 and 37.2) were observed in the high-density cotton spacing of M_3, but these values did not differ statistically from the other main-plot spacings for over years and the pooled mean. For sub-plot treatments, the numerically greatest ginning values (37.8, 36.7 and 37.3) occurred with S_3; however, S_3 was statistically comparable to the remaining sub-plot treatments in across over years and in the pooled mean.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

Table 1. Post-harvest available soil nitrogen, phosphorus and potassium (kg ha^{-1}) of high-density cotton in pigeonpea-based intercropping system as influenced by growth regulators and nitrogen management

Treatments	Nitrogen			Phosphorous			Potassium		
	2023–24	2024–25	Mean	2023–24	2024–25	Mean	2023–24	2024–25	Mean
Main plots									
M_1	228	221	224	32.5	30.1	31.6	259	249	254
M_2	233	227	230	34.3	32.3	33.3	270	262	266
M_3	247	242	244	37.7	35.1	36.4	297	291	294
SE(m)±	6.29	5.54	5.43	1.05	0.97	0.91	7.66	8.17	7.75
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sub plots									
S_1	232	224	228	32.4	30.5	31.5	268	258	260
S_2	235	230	232	35.8	33.3	34.6	272	267	270
S_3	246	242	245	38.4	35.7	37.1	301	293	297
S_4	226	219	223	31.6	29.3	30.5	258	247	252
S_5	233	226	229	33.8	32.7	33.3	269	259	264
S_6	244	240	242	36.7	34.8	35.7	287	282	284
SE(m)±	7.31	8.45	7.45	1.66	1.53	1.41	12.0	10.6	10.7
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interaction									
				M × S					
SE(m)±	12.6	10.23	12.9	2.88	2.12	1.82	20.8	18.5	18.5
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
				S × M					
SE(m)±	13.1	10.56	13.0	2.83	2.04	1.78	20.5	18.7	18.6
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

SE(m) ± = Standard error of mean; CD = Critical difference at p = 0.05; NS = Non-significant Data analysed using analysis of variance (ANOVA) with CD (LSD) at p = 0.05 for split-plot design; treatment effects and their interactions were non-significant

(Initial N - 208.6 (kg ha^{-1}), (Initial P - 21.6 kg ha^{-1}), (Initial K- 301.4 kg ha^{-1})

Lint index

Lint index (g) results (Table 2) showed no significant response to main-plot high-density cotton spacings in paired-row pigeonpea, to growth regulator and nitrogen management treatments in sub-plots, or to their interaction in any year or in the pooled analysis. Nevertheless, the highest mean lint index values (5.81, 5.71 and 5.76) were noted under the 100 × 15 cm spacing and among sub-plots the largest values (5.89, 5.74 and 5.81) were obtained with S_3. These differences were not statistically significant.

Fibre fineness (Micronaire value)

Fibre fineness (micronaire) data appear in Table 2. Micronaire readings were statistically comparable across the main-plot spacing treatments in over individual years and the combined mean. The highest micronaire values (5.80, 5.63 and 5.71) were associated with M_3, but this treatment did not differ significantly from others. Among sub-plot regimes, no significant effect of growth regulator or nitrogen management on fineness was detected; numerically highest micronaire values (5.86, 5.66 and 5.76) occurred with S_3, though these were statistically comparable to the other sub-plot treatments.

Elongation (%)

Elongation percentage results are presented in Table 3. Elongation did not show significant variation due to main-plot high-density spacing, sub-plot growth regulator and nitrogen-management treatments, or their interaction in either year or in pooled data. The greatest elongation means (6.71, 6.51 and 6.61) were noted under M_3 among main plots and the highest values among sub-plots (6.87, 6.59 and 6.73) were observed with S_3; however, these numerical differences were not statistically significant.

Bundle strength

Bundle strength measurements (Table 3.) exhibited no significant difference due to high-density cotton spacing in paired-row of pigeonpea in main plots, growth regulators and nitrogen management treatments in sub-plots and their interaction also found to be non-significant during 2023–24, 2024–25 and in the mean analysis.

However, among main plots highest bundle strength (31.1, 30.2 and 30.6) was obtained with high-density cotton spacing of M_3 and it was comparable with rest of the treatments. Among sub-plots, numerically highest bundle strength (31.7, 30.8 and 31.3) was observed with application of S_3. It was on par with rest of treatments during over years and in the mean data, respectively.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

Table 2. Quality parameters of high-density cotton in pigeonpea-based intercropping system as influenced by growth regulators and nitrogen management

Treatments	Ginning percentage			Lint index			Fibre fineness (Micronaire)		
	2023–24	2024–25	Mean	2023–24	2024–25	Mean	2023–24	2024–25	Mean
Main plots									
M_1	35.3	33.7	34.5	5.50	5.29	5.39	5.35	5.26	5.30
M_2	36.1	34.6	35.4	5.67	5.38	5.52	5.48	5.41	5.45
M_3	37.7	36.6	37.2	5.81	5.71	5.76	5.80	5.63	5.71
SE(m)±	0.70	0.80	0.67	0.09	0.09	0.09	0.15	0.07	0.08
CD (p = 0.05)	2.76	3.14	2.64	0.37	0.40	0.36	0.58	0.27	0.30
Sub plots									
S_1	36.1	34.4	35.3	5.61	5.38	5.50	5.49	5.42	5.46
S_2	37.1	35.8	36.4	5.78	5.63	5.70	5.66	5.56	5.61
S_3	37.8	36.7	37.3	5.89	5.74	5.81	5.86	5.66	5.76
S_4	34.7	33.3	34.1	5.44	5.14	5.29	5.27	5.18	5.22
S_5	35.6	34.0	34.8	5.56	5.30	5.43	5.37	5.32	5.34
S_6	37.0	35.5	36.3	5.67	5.57	5.62	5.61	5.52	5.57
SE(m)±	1.35	1.27	1.24	0.21	0.22	0.20	0.19	0.21	0.17
CD (p = 0.05)	3.91	3.67	3.58	0.62	0.70	0.58	0.54	0.63	0.49
Interaction									
M × S									
SE(m)±	2.34	2.20	2.15	0.37	0.39	0.35	0.32	0.37	0.30
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
S × M									
SE(m)±	2.25	2.16	2.07	0.35	0.36	0.33	0.33	0.35	0.28
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

SE(m) ± = standard error of mean; CD: critical difference at p = 0.05; NS: non-significant. Data analysed using analysis of variance (ANOVA) with CD (LSD) at p = 0.05 for split-plot design; treatment effects and their interactions were non-significant.

M_1: Paired-row of pigeonpea intercropped with high-density planting of cotton at 60 × 15 cm (111111 plants ha^{-1}). M_2: Paired-row of pigeonpea intercropped with high-density planting of cotton at 75 × 20 cm (66666 plants ha^{-1}). M_3: Paired-row of pigeonpea intercropped with high-density planting of cotton at 100 × 15 cm (66666 plants ha^{-1}). S_1: 100 % recommended dose of nitrogen (RDN) + mepiquat chloride 50 ppm at square initiation, peak square formation and flowering stage. S_2: 100 % RDN + mepiquat chloride 50 ppm at square formation and flowering stage. S_3: 125 % RDN + mepiquat chloride 50 ppm at square formation and flowering stage. S_4: 100 % RDN + cycocel 60 ppm at square initiation, peak square formation and flowering stage. S_5: 100 % RDN + cycocel 60 ppm at square formation and flowering stage. S_6: 125 % RDN + cycocel 60 ppm at square formation and flowering stage.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

Table 3. Quality parameters of high-density cotton in pigeonpea-based intercropping system as influenced by growth regulators and nitrogen management

Treatments	Elongation (%)			Bundle strength			Land equivalent ratio (LER)		
	2023–24	2024–25	Mean	2023–24	2024–25	Mean	2023–24	2024–25	Mean
Main plots									
M_1	6.42	6.19	6.31	29.5	27.9	28.6	1.43	1.29	1.36
M_2	6.59	6.30	6.45	30.4	29.3	29.8	1.31	1.18	1.24
M_3	6.71	6.51	6.61	31.1	30.2	30.6	1.28	1.15	1.21
SE(m)±	0.16	0.18	0.13	0.73	0.72	0.71	0.02	0.03	0.02
CD (p = 0.05)	0.62	0.70	0.53	2.87	2.81	2.83	0.06	0.13	0.09
Sub plots									
S_1	6.51	6.28	6.40	29.9	28.8	29.4	1.31	1.17	1.24
S_2	6.66	6.40	6.53	30.9	29.9	30.4	1.38	1.24	1.31
S_3	6.87	6.59	6.73	31.7	30.8	31.3	1.44	1.32	1.38
S_4	6.34	6.17	6.26	28.8	27.2	27.9	1.25	1.12	1.18
S_5	6.47	6.21	6.34	29.6	28.2	28.9	1.29	1.13	1.21
S_6	6.60	6.34	6.47	30.7	29.8	30.3	1.36	1.20	1.28
SE(m)±	0.23	0.20	0.19	1.11	1.02	1.05	0.04	0.05	0.03
CD (p = 0.05)	0.65	0.59	0.55	3.22	2.95	3.02	0.12	0.14	0.10
Interaction									
M × S									
SE(m)±	0.39	0.35	0.33	1.93	1.76	1.81	0.07	0.08	0.06
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
S × M									
SE(m)±	0.38	0.37	0.33	1.91	1.76	1.80	0.07	0.08	0.06
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

SE(m) ± = standard error of mean; CD: critical difference at p = 0.05; NS: non-significant. Data analysed using analysis of variance (ANOVA) with CD (LSD) at p = 0.05 for split-plot design; treatment effects and their interactions were non-significant.

M_1: Paired-row of pigeonpea intercropped with high-density planting of cotton at 60 × 15 cm (111111 plants ha^{-1}). M_2: Paired-row of pigeonpea intercropped with high-density planting of cotton at 75 × 20 cm (66666 plants ha^{-1}). M_3: Paired-row of pigeonpea intercropped with high-density planting of cotton at 100 × 15 cm (66666 plants ha^{-1}). S_1: 100 % recommended dose of nitrogen (RDN) + mepiquat chloride 50 ppm at square initiation, peak square formation and flowering stage. S_2: 100 % RDN + mepiquat chloride 50 ppm at square formation and flowering stage. S_3: 125 % RDN + mepiquat chloride 50 ppm at square formation and flowering stage. S_4:100 % RDN + cycocel 60 ppm at square initiation, peak square formation and flowering stage. S_5:100 % RDN + cycocel 60 ppm at square formation and flowering stage. S_6: 125 % RDN + cycocel 60 ppm at square formation and flowering stage.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

Results revealed that quality parameters (GP, lint index, fibre fineness, elongation percentage and bundle strength) were found non significantly (CD = NS) for the main plots, the sub-plots and their interaction, However, numerically higher values may be noted for GP, lint index, fibre fineness, elongation percentage and bundle strength were observed with high-density cotton spacing of M_3. This may be explained by genetic and environmental factors that influence the quality parameters of cotton. Comparable outcomes were stated by previous researchers, they stated that quality parameters were not affected significantly by different crop geometry and nitrogen doses (10). Hence differences in quality parameters were not registered significantly. Comparable results were reported in previous studies which stated that quality characters are mostly governed by genetic makeup of the cotton plant and they were not changed by external application of chemicals (11). Another researchers stated that different plant spacing did not affect the micronaire values (12), which was in agreement with the previous findings (10). Quality parameters such as staple length, micronaire, uniformity ratio, elongation percentage and tenacity were not significantly altered by population density and foliar nutrients application as stated previously (13). Similar studies stated that quality parameters like ginning percent and lint index were not significantly influenced by varying crop geometries and foliar application of growth retardants (14).

Among sub-plots the quality parameters like ginning percentage, lint index, fibre fineness, elongation percentage and bundle strength were not significantly influenced by growth regulators and nitrogen management, however highest quality parameters were noted with application of S_3 during 2023–24, 2024–25 and in the mean data. Fibre quality parameters are mainly determined by genetic makeup of the cotton variety. Agronomic practices such as plant density, plant growth regulators application and nitrogen management mainly affect yield-related traits rather than quality parameters. Comparable results were observed in previous reports (15, 16). Nitrogen levels and plant densities did not influence the ginning per cent of the cotton as stated previously (17). The quality parameters are the genetic characters that are not modified by organic nutrient management but numerically show higher with inorganic application of fertilisers. These outcomes agree with the previous studies (18).

Economics

The data in relation to cost of cultivation, gross returns, net returns and B : C ratio are furnished in Fig. 1 A and B.

Gross returns

Analysis of main-plot treatments showed that the highest gross returns (Table 4.) were achieved with the M_1 in the paired-row pigeonpea system, with values of ₹259807, ₹226887 and ₹243347 ha^{-1} for 2023–24, 2024–25 and the pooled mean, respectively. The next best returns were noted under M_2, which produced gross returns of ₹223586, ₹202054 and ₹212820 ha^{-1} for the two years and mean. The lowest gross returns occurred with M_3, at ₹213346, ₹190126 and ₹201736 ha^{-1} for 2023–24, 2024–25 and the combined mean, respectively.

For the sub-plot treatments, (Table 4) the greatest gross returns (₹260016, ₹227162 and ₹243589 ha^{-1} for 2023–24, 2024–25 and mean) were obtained with S_3. These values were statistically comparable to those from S_2 and S_6. The lowest gross returns were associated with S_4, which gave ₹208871, ₹187923 and ₹198397 ha^{-1} for 2023–24, 2024–25 and the pooled mean.

Overall, the superior gross returns under M_1 likely reflect the greater plant population per unit area in M_1 planting, which increased seed cotton yield relative to wider spacings. Pigeonpea deep-rooted nature and nitrogen-fixing ability reduce competition with cotton for nutrients and improve soil fertility, enabling high-density cotton to perform well it results in increasing seed cotton yield ultimately gross returns. These comparable results were stated by earlier researchers who stated that spatial arrangement (such as paired or strip rows) minimises competition for light and water, optimising growth of over crops it results in higher gross and net returns were noted in demo cotton + red gram intercropping over check sole cotton, which might be due to higher cotton equivalent yield, lower cost of cultivation (19). The present findings agree with their results.

Among sub-plots results revealed that higher gross returns were noted with application of S_3. This may be attributed due to application of more nutrients combined with growth regulators resulted higher seed cotton yield obtained in this treatment. Mepiquat chloride spray along with application of a higher fertiliser dose noted significantly higher gross returns, net returns and B : C ratio. Similar results were reported previously (20). Nitrogen and growth regulator application in such systems further optimise plant growth, leading to better utilisation of available resources and higher total output per unit area. Similar results were reported by previous researchers (21).

Net returns

Analysis of main-plot treatments (Table 4.) showed that the highest net returns were obtained with M_1 in the paired-row pigeonpea system, giving ₹167254, ₹137718 and ₹152486 ha^{-1} for 2023–24, 2024–25 and the pooled mean, respectively. The M_2 produced the next highest net returns of ₹134593, ₹115944 and ₹125269 ha^{-1} for the two years and the mean. The lowest net returns were noted under M_3, at ₹126353, ₹105517 and ₹115935 ha^{-1} for 2023–24, 2024–25 and the combined mean.

Among subplot treatments (Table 4), S_3 achieved the greatest net returns: ₹169942, ₹140087 and ₹155015 ha^{-1} for 2023–24, 2024–25 and the pooled mean. These values were statistically comparable to those from S_2 and S_6. The lowest net returns were associated with S4, which gave ₹119751, ₹101603 and ₹110677 ha^{-1} for 2023–24, 2024–25 and the mean.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

Overall, the superior net returns under M_1 likely reflect the higher plant population per unit area and improved resource capture, which increased seed cotton output and improved profitability on a per-hectare basis. They stated that higher gross and net returns were noted in demo cotton + red gram intercropping over check sole cotton, which might be due to higher cotton equivalent yield, lower cost of cultivation.

Similarly, the application of S_3 enhanced economic returns relative to several other treatments. The highest net returns were due to higher seed cotton yield obtained per hectare due to increased levels of nitrogen, efficient nutrient use and application of growth regulators. These comparable results were also reported earlier which stated that elevated nitrogen level which enhanced the dry matter production which facilitated a greater photosynthesis, thereby leading to boost in seed cotton yield which leads to highest gross returns and net returns (21). Similar findings were reported in previous studies (22).

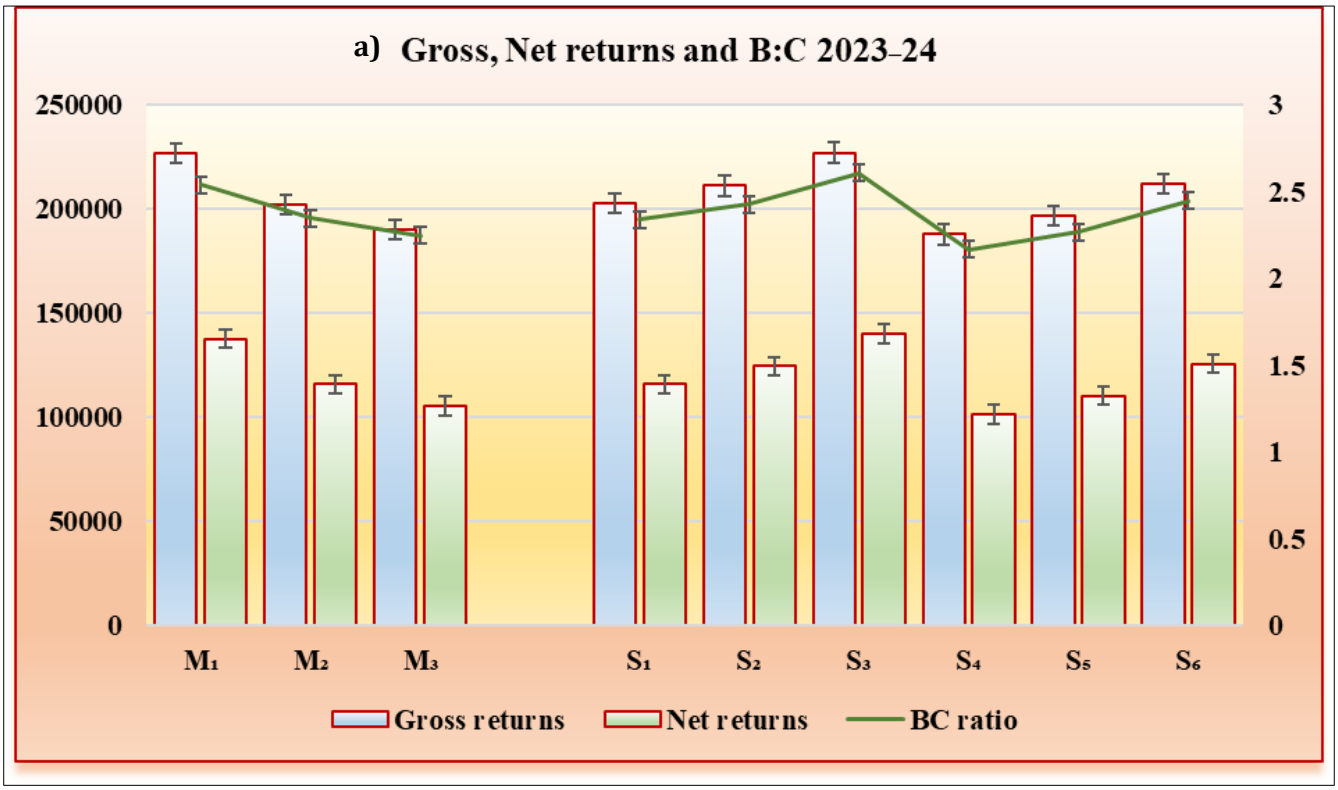
Benefit–cost ratio

Across the main-plot treatments, the highest B : C ratios were observed with the closest planting configuration (M_1): 2.81 in 2023–24, 2.54 in 2024–25 and 2.68 for the two-year mean. The M_2 produced the next-best B : C values (2.51, 2.35 and 2.43) and these did not differ significantly from M_3 in either individual year or the mean.

For subplot treatments, the more B : C ratios were obtained when S_3: 2.88 in 2023–24, 2.61 in 2024–25 and 2.74 on average. This treatment was statistically comparable to over S_2 and S_6 across years and in the mean. The lowest returns were noted with S_4, which showed B : C ratios of 2.34, 2.17 and 2.26 for 2023–24, 2024–25 and the mean, respectively.

Overall, the paired-row system with the highest planting density (M_1) gave the best economic returns, likely reflecting the yield advantages of denser cotton planting within pigeonpea inter-rows. Over inter crops together utilise resources like light, water and nutrients more efficiently reducing cost per unit of production and increasing the B : C ratio than either crop grown alone. Comparable results agreed with the outcomes of earlier reports (23). Increase in profitability was mainly owing to higher seed-cotton yield as reported previously (23, 24).

The subplot data showed that the highest B : C ratio was observed with the application of S_3. This likely occurred because efficient utilisation of applied nutrients along with growth regulators led to a higher seed cotton yield per hectare, which in turn resulted in a higher B : C ratio. Comparable observations were stated by previous researchers, who stated that a higher B : C ratio was due to higher seed cotton yields and net returns compared with other treatments (25). Another researchers stated that higher returns and lower cultivation cost were obtained in the cotton + red gram intercropping system over sole cotton, ultimately increasing the benefit–cost ratio in the demonstration field compared with the check (26, 27).



© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

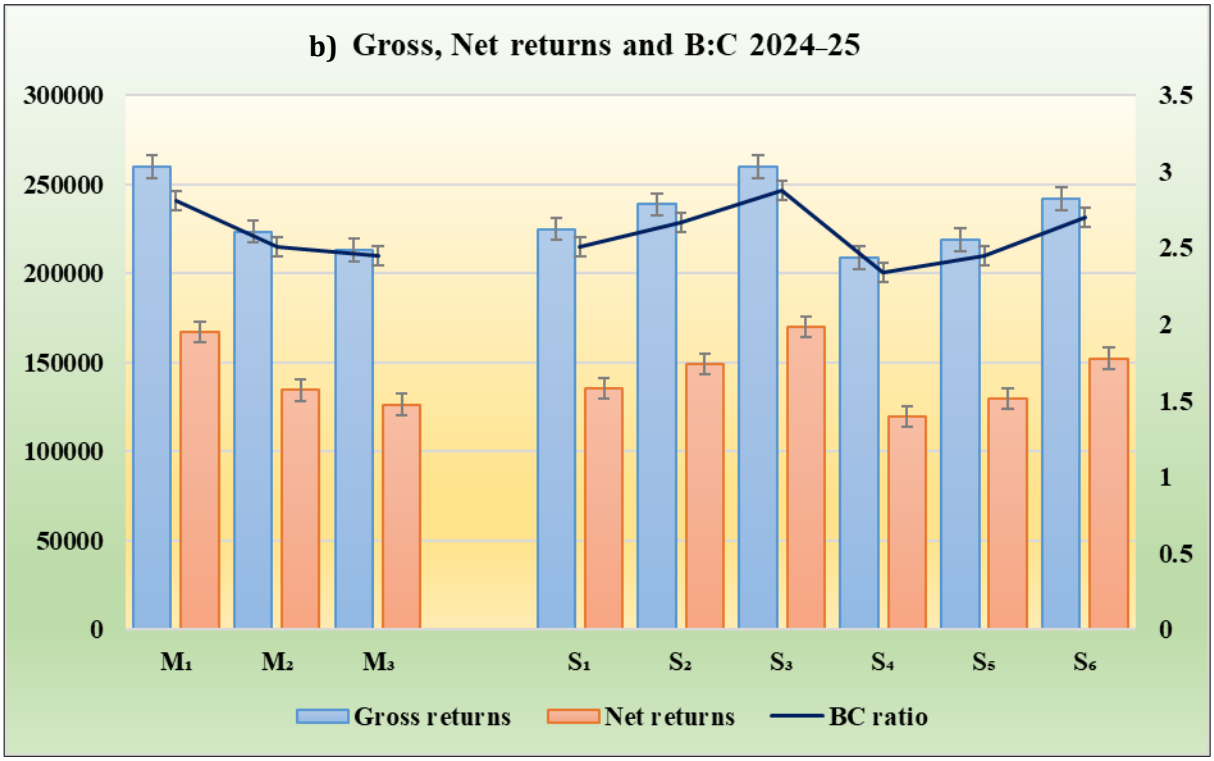


Fig. 1. Gross returns, net returns, benefit–cost ratio of high-density cotton in paired-row of pigeonpea as influenced by growth regulators and nitrogen management during a) 2023–24; b) 2024–25.

M_1: Paired-row of pigeonpea intercropped with high-density planting of cotton at 60 × 15 cm (111111 plants ha^{-1}). M_2: Paired-row of pigeonpea intercropped with high-density planting of cotton at 75 × 20 cm (66666 plants ha^{-1}). M_3: Paired-row of pigeonpea intercropped with high-density planting of cotton at 100 × 15 cm (66666 plants ha^{-1}). S_1: 100 % recommended dose of nitrogen (RDN) + mepiquat chloride 50 ppm at square initiation, peak square formation and flowering stage. S_2: 100 % RDN + mepiquat chloride 50 ppm at square formation and flowering stage. S_3: 125 % RDN + mepiquat chloride 50 ppm at square formation and flowering stage. S_4: 100 % RDN + cycocel 60 ppm at square initiation, peak square formation and flowering stage. S_5: 100 % RDN + cycocel 60 ppm at square formation and flowering stage. S_6: 125 % RDN + cycocel 60 ppm at square formation and flowering stage.

Table 4. Gross returns (₹ ha^{-1}) Net returns (₹ ha^{-1}) of high-density cotton in pigeonpea-based intercropping system as influenced by growth regulators and nitrogen management

Treatments	Cost of cultivation			Gross returns			Net returns		
	2023–24	2024–25	mean	2023–24	2024–25	mean	2023–24	2024–25	mean
Main plot									
M_1	92553	89170	90861	259807	226887	243347	167254	137718	152486
M_2	88993	86109	87551	223586	202054	212820	134593	115944	125269
M_3	86993	84609	85801	213346	190126	201736	126353	105517	115935
SE(m)±	-	-	-	4776	5308	4553	4776	5308	4553
CD (p = 0.05)	-	-	-	18755	20843	17877	18755	20843	17877
Sub plots									
S_1	89570	86670	88120	225032	202678	213855	135462	116008	125735
S_2	89570	86670	88120	238802	211252	225027	149232	124582	136907
S_3	90074	87074	88574	260016	227162	243589	169942	140087	155015
S_4	89120	86320	87720	208871	187923	198397	119751	101603	110677
S_5	89120	86320	87720	218872	196716	207794	129752	110396	120074
S_6	89624	86734	88174	241885	212404	227144	152261	125680	138970

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

SE(m)±	-	-	-	6749	6145	4561	6749	6145	4561
CD (p = 0.05)	-	-	-	19493	17748	13174	19493	17748	13174
Interaction									
M × S									
SE(m)±	-	-	-	11689	7164	7901	11690	10643	7900
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
S × M									
SE(m)±	-	-	-	11691	7605	8529	11692	11072	8529
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

SE(m)±: standard error of the mean; CD: critical difference at the 5 % level of significance (p = 0.05); NS: non-significant. M_1–M_3: main-plot treatments; S_1–S_6: sub-plot treatments; M × S and S × M: treatment interactions.

Pigeonpea seed yield

Among the main plots, (Table 5) the highest seed yield (1286, 1085 and 1186 kg ha^{-1}) was noted with paired row of pigeonpea in high density cotton spacing of M_1, however it was comparable with paired row of pigeonpea in high density cotton spacing of M_2 during over years and in the average over years data respectively. Among sub-plots, highest seed yield (1271, 1083 and 1178 kg ha^{-1}) was registered with treatment S_3, however it was statistically at par with rest of the treatments during over years and in the average over years data respectively.

Seed cotton yield

Among the main plots data clarified that high density cotton spacing of M_1 had noted significantly highest seed cotton yield (2285, 2036 and 2161 kg ha^{-1}) during 2023–24, 2024–25 and in the average over years data results respectively (Table 5). On the other hand, the lowest seed cotton yield (1943, 1751 and 1846 kg ha^{-1}) was noted with high density cotton spacing of M_3, however it was comparable with high density cotton spacing of M_2 which had seed cotton yield of 1982, 1807 and 1894 kg ha^{-1} during over years and in the average over years results, respectively. Among the sub-plots, seed cotton yield was significantly influenced by growth regulators and nitrogen management during over years of study. Data revealed that application of S_3 noted highest seed cotton yield of 2303, 2042 and 2172 kg ha^{-1}, however it was comparable with application of S_2 and with application of S_6 during over years and in the average over years data results, respectively.

The higher gross returns, net returns and B : C ratio noted under M_1 may be explained through improved population-based productivity and greater resource capture per unit area. Under high-density planting, increased plant population enhanced cumulative interception of photosynthetically active radiation, resulting in greater canopy photosynthesis and dry matter production per unit land area. In paired-row pigeonpea intercropping, this effect may have been further supported by spatial complementarity, where cotton exploited upper canopy light resources while pigeonpea contributed to improved rhizosphere functioning and partial biological nitrogen enrichment. The increased sink size through greater boll-bearing plants per hectare likely contributed to higher seed cotton yield and consequently superior economic returns. The beneficial effect of S_3 appears to be associated with improved source–sink balance and canopy efficiency. Higher nitrogen availability likely promoted chlorophyll content, photosynthetic activity and assimilate production, while mepiquat chloride, through suppression of excessive vegetative growth via inhibition of gibberellic acid biosynthesis, reduced unproductive vegetative sinks and diverted assimilates towards reproductive structures. Application at square formation and flowering stages was particularly effective because these stages coincide with peak boll load establishment and strong sink demand.

Table 5. Pigeonpea yield (kg ha^{-1}) and Seed cotton yield (kg ha^{-1}) in high-density cotton in pigeonpea-based intercropping system as influenced by growth regulators and nitrogen management

Treatments	Pigeonpea seed yield			Seed cotton yield		
	2023–24	2024–25	Mean	2023–24	2024–25	Mean
Main plots						
M_1	1286	1085	1186	2285	2036	2161
M_2	1093	973	1032	1982	1807	1894
M_3	994	867	931	1943	1751	1846
SE(m)±	47.5	39.5	40.2	46.9	55.1	46.9
CD (p = 0.05)	NS	NS	NS	184.3	214.0	184.2

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

Sub plots						
S_1	1092	954	1022	2002	1836	1919
S_2	1116	982	1049	2169	1925	2047
S_3	1271	1083	1178	2303	2042	2172
S_4	1008	870	939	1864	1716	1790
S_5	1061	923	992	1948	1784	1866
S_6	1194	1037	1115	2131	1884	2008
SE(m)±	55.5	51.7	44.6	70.8	58.1	47.1
CD (p = 0.05)	NS	NS	NS	204.6	167.8	136.0
Interaction						
M × S						
SE(m)±	4.33	3.81	76.6	108.2	100.6	81.5
CD (p = 0.05)	NS	NS	NS	NS	NS	NS
S × M						
SE(m)±	4.51	3.70	81.6	108.6	106.8	88.0
CD (p = 0.05)	NS	NS	NS	NS	NS	NS

SE(m)±: standard error of the mean; CD: critical difference at the 5 % level of significance (p = 0.05); NS: non-significant.

This arrangement likely improved cumulative light interception, canopy photosynthesis and dry matter production per unit land area, which is consistent with the higher LER and economic returns noted in the present study. Comparable advantages of paired or strip-row arrangements in cotton-pigeonpea systems were reported by previous researchers, who attributed yield gains to better resource-use efficiency and reduced competition between component crops (28, 29). The present pattern also agrees with previous reports that observed superior returns from cotton-red gram intercropping under rainfed Telangana (29) and another study highlighted that agronomic interference is lowered when cotton and pigeonpea are spatially arranged to exploit different canopy strata and rooting depths (26). Further, the deep-rooted and nitrogen-fixing nature of pigeonpea can partially sustain rhizospheric fertility and buffer cotton against nutrient stress, while cotton benefits from improved soil structure and a more favourable microenvironment, helping explain the paired-row advantage over narrower or less coordinated arrangements. The synergistic interaction between higher nitrogen supply and mepiquat chloride likely optimised canopy architecture by moderating excessive vegetative growth commonly induced by elevated nitrogen. A compact and efficient canopy improves light distribution within the crop profile, enhances photosynthetic efficiency of lower leaves and improves assimilate translocation to reproductive sinks. This physiological balance may explain application 125 % RDN + mepiquat chloride at square formation and flowering stage consistently noted higher numerical parameters along with maximum economic returns.

The agronomic and economic interference between cotton and pigeonpea observed that competitive interactions could limit individual crop yields under conventional densities; by contrast, the paired-row pigeonpea with high-density cotton minimises direct inter-specific competition through spatial separation while preserving the compatible biological nitrogen enrichment of pigeonpea, thereby converting the competitive interference into productive facilitation. Similarly, demonstrations conducted by previous researchers under rainfed conditions in Telangana reported higher gross and net returns from cotton–red gram (pigeonpea) intercropping compared with sole cotton. These findings highlight the economic potential of cotton–pigeonpea intercropping systems under the Vertisol conditions of the SAT of peninsular India (18). The fibre quality parameters remain primarily under genetic control and are not substantially modified by agronomic interventions. Neither planting geometry nor nitrogen and growth regulator treatments significantly altered GP, lint index, micronaire, elongation or bundle strength, regardless of the significant economic differentials noted among treatments as reported previously (13).

Application of combined optimised nitrogen levels with mepiquat chloride to improve canopy regulation and reproductive efficiency. About 125 % RDN along with mepiquat chloride at square formation and flowering stage improved source-sink balance, reduced excessive vegetative growth and enhanced assimilate partitioning towards boll development. This was not addressed in earlier intercropping studies, thereby highlighting the advancement of the present

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

recommendation over traditional kharif cotton–pigeonpea systems.

The present response is consistent with previous reports, which stated that higher plant density under HDPS increased seed-cotton yield and net realisation despite lower values of several plant-level growth and yield attributes (23). Similarly, working under the agro-climatic conditions of Telangana, observed greater seed-cotton yield and economic returns at higher planting density (29). These outcomes support the interpretation that the higher economic execution of M_1 in the present study was associated primarily with greater productivity per unit land rather than necessarily superior productivity of individual cotton plants.

The paired-row arrangement of pigeonpea may also have contributed to better spatial organisation of the component crops. In an intercropping system, the spatial distribution of plants can influence the degree of competition for light, nutrients and soil resources. Successful HDPS depends on maintaining an appropriate plant architecture and balancing vegetative and reproductive growth through suitable genotype, planting geometry and canopy management (29) Thus, the superior execution of M_1 in the present study may be interpreted as a combined effect of higher population density and the spatial configuration provided by paired-row pigeonpea rather than as a simple effect of closer cotton spacing alone.

Nitrogen is required for leaf development, chlorophyll formation, protein synthesis and maintenance of photosynthetically active tissues. Adequate nitrogen availability can therefore support assimilate production during the reproductive phase. However, excessive nitrogen availability may also promote prolonged vegetative growth in indeterminate cotton. Under high-density conditions, excessive vegetative development can intensify competition among plants and potentially reduce the efficiency of reproductive growth (27).

Mepiquat chloride provides a contrasting physiological effect by suppressing excessive vegetative elongation and promoting a more compact plant architecture. Thus, the response observed with S_3 may reflect a better balance between vegetative growth and reproductive development when the additional nitrogen supply was accompanied by growth regulation. Mepiquat chloride was applied at square formation and flowering, stages at which cotton plants undergo substantial transition from vegetative development towards reproductive growth. Regulation of excessive shoot elongation during this period may help maintain a compact canopy and favour reproductive development. Similar findings were observed in previous studies (29, 20).

Conclusion

The paired-row pigeonpea-cotton system with a dense cotton planting of 60 × 15 cm (M_1) delivered the best economic and land-use outcomes. Over the two-year period it produced the highest average gross return (₹243347 ha^{-1}), net return (₹152486 ha^{-1}), benefit : cost (B : C) ratio (2.68) and land equivalent ratio (LER = 1.36). Although the wider 100 × 15 cm spacing (M_3) tended to give marginally better fibre quality, it was outperformed by M_1 for profitability and efficient use of land.

Among the subplot nutrient and growth-regulator treatments, 125 % of the recommended nitrogen dose combined with mepiquat chloride at 50 ppm applied at square formation and flowering (S_3) achieved the top execution, recording mean gross returns of ₹243589 ha^{-1}, net returns of ₹155015 ha^{-1}, a B : C of 2.74 and LER of 1.38, in addition to superior fibre characteristics. The poorest results for returns, B : C ratio and fibre quality were associated with the treatment receiving 100 % recommended dose of nitrogen (RDN) plus cycocel 60 ppm applied at square initiation, peak square formation and flowering (S_4).

The present study demonstrated that paired-row pigeonpea–cotton intercropping combined with high-density cotton planting and appropriate crop growth regulator management improved the agronomic and economic execution of the system under the experimental rainfed conditions on semi-arid Vertisols. Among the planting configurations evaluated, paired-row pigeonpea with cotton planted at M_1 noted higher economic returns and land-use advantage than the other planting configurations. The higher LER (> 1) across the intercropping treatments indicated a land-use advantage under the experimental conditions. Further studies incorporating the soil moisture monitoring, crop water use measurements and water use efficiency assessments across contrasting environments would be useful to establish the water related mechanisms underlying the execution of the pigeonpea-cotton intercropping system.

Acknowledgements

The authors express their sincere gratitude to the Agricultural Research Station, Tandur, Vikarabad, Telangana, for providing the necessary facilities and support. The authors also extend their appreciation to the staff at the experimental site for their valuable assistance throughout the research work.

Authors' contributions

DV and CSR conceived and conducted the experiment, collected the data and prepared the initial manuscript draft. CSR and CS contributed to conceptualisation, supervision, interpretation of results and manuscript editing. CS also contributed to the methodology and critical revision of the manuscript. TRP provided supervision and technical guidance, conducted soil and plant analyses and reviewed the manuscript. DV and KS contributed to data analysis, literature review and

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

manuscript editing. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Grammarly tool to check correcting grammar and spelling mistakes, improving sentence structure and clarity. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

1. Food and Agriculture Organization. FAOSTAT 2024. (ON3901).
2. Rani CS, Sudhakar C, Rani SK. Effect of different spacing within a pair and between pairs on growth and productivity of pigeonpea crop (*Cajanus cajan* (L.) Millsp.) in a paired-row planting system. Int J Agric Sci Res. 2019;1(10):1–6. ISSN: 2250-0057 (online), 2321-0087 (print).
3. Maitra S, Ray DP. Enrichment of biodiversity, influence in microbial population dynamics of soil and nutrient utilization in cereal-legume intercropping systems: a review. Int J Bio-resource Sci. 2019;6(1):11–19. https://doi.org/10.30954/2347-9655.01.2019.3
4. Maitra S, Ghosh DC, Sounda G, Jana PK, Roy DK. Productivity, competition and economics of intercropping legumes in finger millet at different fertility levels. Indian J Agric Sci. 2001;70(12):824–8. https://epubs.icar.org.in/index.php/IJAgS/article/view/28741
5. Potdar MV, Anders MM, Sharma M. Yield advantages and economic returns from pigeonpea/cotton strip intercropping rotations on a Vertisol in the Indian semi-arid tropics. Series Int Agric Res. 1996:58–72. https://oar.icrisat.org/4762/1/CP_1123.pdf
6. Bhardwaj R, Kushwaha HS, Birla J, Turkar Y, Patidar K. Studies on nutrient management in pigeon pea (*Cajanus cajan* (L.) Millsp.) based intercropping system. Legume Res. 2023;46(8):1048–53. https://doi.org/10.18805/LR-3947
7. Khan NU, Marwat KB, Hassan G, Farhatullah, Batool S, Makhdoom K, et al. Genetic variation and heritability for cotton seed, fibre and oil traits in *Gossypium hirsutum* L. Pak J Bot. 2010;42(1):615–25. https://www.pakbs.org/pjbot/PDFs/42(1)/615.pdf
8. Verna VP, Kaur R, Shivay YS. Yield and quality parameters of Bt cotton as affected by nitrogen dose and its scheduling. Int J Curr Microbiol Appl Sci. 2017;6(3):901–6. https://doi.org/10.20546/ijcmas.2017.603.105
9. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York: John Wiley; 1984. ISBN: 0-471-87931-2.
10. Malik K, Mehta AK, Thakral SK. Quality parameters, nitrogen content and uptake of cotton cultivar H-1098 and nutrient status of soil influenced by different spacing and nitrogen application. Int J Curr Microbiol Appl Sci. 2021;10(1):3058–66. https://www.ijcmas.com/10-1-2021/Kapil%20Malik,% 20et% 20al.pdf
11. Saravanan M, Venkitaswamy R, Rajendran K. Influence of foliar nutrition on seed cotton yield and quality of Bt cotton. Madras Agric J. 2012;99:1. https://doi.org/10.5555/20123213291
12. Nadeem MA, Ali A, Tahir M, Naeem M, Chadhar AR, Ahmad S. Effect of nitrogen levels and plant spacing on growth and yield of cotton. Pak J Life Soc Sci. 2010;8:121–4. https://pjlss.edu.pk/pdf_files/2010_2/121-124%20(dr.%20Athar%202).pdf
13. Sapkota BR, Adams CB, Kelly B, Rajan N, Ale S. Plant population density in cotton: addressing knowledge gaps in stand uniformity and lint quality under dryland and irrigated conditions. Field Crops Res. 2023;290:108762. https://doi.org/10.1016/j.fcr.2022.108762
14. 14. Maheswari MU, Krishnasamy SM, Kumar M, Sakthivel N. Effects of plant density and growth retardants on yield and quality of machine-sown cotton. Environ Ecol. 2019;37(3):777–85. ISSN: 0971-5878.
15. Karthikeyan PK, Jayakumar R. Nitrogen and chlormequat chloride on cotton cultivar. In: Plant nutrition: food security and sustainability of agro-ecosystems through basic and applied research. Dordrecht: Springer; 2001. p. 806–7. https://doi.org/10.1007/0-306-47624-X_392
16. Sawan ZM, Mahmoud MH, El-Guibali AH. Response of yield, yield components and fibre properties of Egyptian cotton (*Gossypium barbadense* L.) to nitrogen fertilization and foliar-applied potassium and mepiquat chloride. J Cotton Sci. 2006;10:224–34. https://www.cotton.org/journal/2006-10/4/224.cfm
17. Nagender T, Reddy DR, Rani PL, Sreenivas G, Surekha K, Gupta A, et al. Response of nitrogen fertilization and plant densities on Bt and non-Bt cotton hybrids. Int J Curr Microbiol Appl Sci. 2017;6(9):3199–207. https://doi.org/10.20546/ijcmas.2017.609.395
18. Patil VV, Solanke AV, Mahajan RV, Wagh SP, Gajbe ND. Effect of quality parameters of desi cotton as influenced by different nutrient sources. Indian J Agric Res. 2023;57(4):456–63. https://doi.org/10.18805/IJAR.A-4
19. Sridhar K, Archana P, Aruna K, Rani JS. Demonstration of cotton + redgram intercropping system under rainfed conditions of Telangana state. Int J Adv Biochem Res. 2024;8(6):6–9. https://doi.org/10.33545/26174693.2024.v8.i6Sa.1242
20. Chavan M, Rao S, Desai BK, Koppalkar BG. Influence of management practices on yield and economics of compact cotton grown under HDPS in irrigated ecosystem. Int J Curr Microbiol Appl Sci. 2020;9(2):235–40. https://doi.org/10.20546/ijcmas.2020.902.028
21. Kumar P, Karle AS, Singh D, Verma L. Effect of high-density planting system (HDPS) and varieties on yield, economics and quality of desi cotton. Int J Curr Microbiol Appl Sci. 2017;6(3):233–8. https://doi.org/10.20546/ijcmas.2017.603.025
22. Singh H, Singh G, Lal M. Growth and productivity of Bt cotton (*Gossypium hirsutum*) under row spacing and nitrogen doses. Indian J Agric Sci. 2023;93(12):1380–3. https://doi.org/10.56093/ijas.v93i12.141399
23. Blaise D, Majumdar G, Tekale KU. On-farm evaluation of fertilizer application and conservation tillage on productivity of cotton + pigeonpea strip intercropping on rainfed Vertisols of central India. Soil Tillage Res. 2005;84(1):108–17. https://doi.org/10.1016/j.still.2004.07.009
24. Patel BR, Chaudhari PP, Chaudhary MM, Patel KN. Effect of mepiquat chloride on growth parameters and yield of Bt cotton under high-density planting system. Indian J Agron. 2021;66(1):67–73. https://doi.org/10.59797/ija.v66i1.2838

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.
https://doi.org/10.14719/pst.16142

25. Ghule PL, Palve DK, Jadhav JD, Dahiphale VV. Plant geometry and nutrient levels effect on productivity of Bt cotton. Int J Agric Sci. 2013;9(2):486–94.
26. Srikala K, Reddy TP, Reddy K, Mahadevappa SG. Effect of nitrogen levels and mepiquat chloride on yield and economics of HDPS cotton. Int J Environ Clim Change. 2023;13(11):1960–7. https://doi.org/10.9734/ijecc/2023/v13i113354
27. Oad FC, Siddiqui MH, Buriro UA. Agronomic and economic interference between cotton (*Gossypium hirsutum* L.) and pigeon pea (*Cajanus cajan* L.). J Agron. 2007;6(1):199–203. https://doi.org/10.3923/ja.2007.199.203
28. Manibharathi S, Somasundaram S, Panneerselvam P, Alagesan S, Veerasamy R, Narayanan MB. Exploring the impact of high-density planting system and deficit irrigation in cotton (*Gossypium hirsutum* L.): a comprehensive review. J Cotton Res. 2024;7:28. https://doi.org/10.1186/s42397-024-00190-1
29. Selvamani S, Kumaresan D, Ravikesavan R, Kannan N, Manikanda Boopathi N, Sakthivel N. Comprehensive insights on evolving ideal plant type for high-density planting of cotton in India. J Cotton Res. 2026;9:1. https://doi.org/10.1186/s42397-025-00246-w
30. Kavya D, Kumari CP, Sreenivas G, Prakash TR, Triveni S. Optimisation of planting densities and nitrogen requirement for Bt cotton under high-density planting system. Int J Bio-resour Stress Manag. 2023;14(3):436–42. https://doi.org/10.23910/1.2023.3309a

Additional information

Peer review: Publisher thanks the Sectional Editor and anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information: Available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy.

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting.

Copyright: © The Author(s). This is an open-access article distributed under the Creative Commons Attribution License CC BY 4.0.

Publisher information: Plant Science Today is published by Horizon e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.

© The Author(s) 2026. Creative Commons CC BY 4.0. Published by Horizon e-Publishing Group.

https://doi.org/10.14719/pst.16142