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RESEARCH ARTICLE

Effect of nutrients and spacing on growth characters, yield attributes and yield under high-density planting system of cotton

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Abstract

Field experiments were conducted at the farmer's field, Madathanoor village, Pochamapalli taluk, Krishnagiri district, from August to January 2023-2024 and at the Experimental Farm, Department of Agronomy, Faculty of Agriculture, Annamalai University, from January to June 2024 to study the yield maximization through agronomic strategies under high-density planting system (HDPS) of cotton. The field experiment was laid out in a factorial randomized block design with three replications. The experiment comprised 12 treatment combinations containing three levels of nutrients and four levels of spacing. The nutrient levels of N_1- 80:40:40 nitrogen, phosphorus, potassium (NPK) kg ha^{-1}, N_2 - 100:50:50 NPK kg ha^{-1} and N_3 - 120:60:60 NPK kg ha^{-1} recommended doses of fertilizers (RDF) were tried with S_1 - 60 x 10 cm, S_2 - 60 x 15 cm, S_3 - 70 x 10 cm and S_4 - 100 x 10 cm spacing. The results revealed that the combination of 120:60:60 NPK kg ha^{-1} + 60 x 10 cm spacing registered higher plant height. Also, the combination of 120:60:60 NPK kg ha^{-1} + 100 x 10 cm spacing registered higher leaf area index (LAI) and dry matter production (DMP), yield attributing characters (sympodial branches plant^{-1}, number of squares plant^{-1} and boll weight) and seed cotton yield. In controversially, the combination of 120:60:60 NPK kg ha^{-1} + 60 x 10 cm spacing registered higher plant height.

Keywords

competition; congestion; dry matter production; photosynthesis

Introduction

Cotton is an important commercial fiber crop in India, playing a significant role in agriculture and industrial development. Often referred to as the "King of Fiber Crops" (1) and "White Gold" due to its high economic value, cotton is pivotal for industrial growth, employment generation and economic development. It employs over 70 million people in India (2). Globally, cotton is renowned as one of the finest fibers and raw materials for the textile industry, with an annual economic value of approximately $600 billion (3). This natural fiber is grown as an annual crop worldwide, mostly used as an industrial commodity, lint, oil and animal feed (4). Cotton and its byproducts have multiple uses, including serving as a nutritional supplement source, oil-free livestock seed cake and contributing organic matter after harvest (5).

Cotton is cultivated in approximately 80 countries worldwide, with 123 countries engaged in cotton-based activities (6). It covers an area of 34.6 million hectares, producing around 121.5 million bales. Among the top cotton-producing nations, India, China, the United States and Brazil account for 74% of the world's total cotton production (7). China leads in cotton consumption, utilizing 36.5 million bales and contributing one-third of the total spinning mills. India follows in second place, consuming 24.5 million bales (8). India ranks first globally in cotton acreage, with 12.07 million hectares under cotton cultivation, representing approximately 36% of the world's total area of 33.3 million hectares. In Tamil Nadu, cotton is grown on 0.156 million hectares, producing 3.56 lakh bales with an average productivity of 388 kg per hectare (9). The major cotton-producing districts in Tamil Nadu, *viz.* Perambalur, Salem, Trichy, Dharmapuri, Krishnagiri, Ariyalur, Coimbatore, Madurai and Cuddalore.

India is projected to produce 42.35 million bales of cotton by 2030, driven by increasing consumer demand (10). However, India's seed cotton production per unit area remains significantly lower than many other cotton-growing countries. Low plant populations and insufficient fertilizer application are the two primary factors of the country's low cotton crop productivity. Research efforts are being made to address these issues, including maintaining adequate plant density, using appropriate fertilizers and applying growth regulators. New varieties suitable for HDPS have also been developed and released. To improve productivity, optimize profits and manage rising production costs, adopting a HDPS is a viable alternative. This method involves adjusting row spacing, plant density and the spatial arrangement of cotton plants to achieve higher yields. The HDPS technique, known as 'Ultra Narrow Row' cotton, was developed by the Central Institute of Cotton Research in Nagpur in 2010. This system, which involves planting cotton very closely per unit area, is seen as a promising alternative for enhancing productivity and profitability, increasing efficiency, reducing input costs and minimizing risks in India's cotton production system. Additionally, HDPS promotes immediate canopy closing and reduces soil water evaporation, making it an effective strategy to address water scarcity challenges.

Traditional cotton varieties and hybrids typically have a wider, taller and more branched crop canopy, requiring multiple pickings due to continuous boll setting and bursting, which makes them unsuitable for mechanized harvesting. In contrast, compact cotton varieties address these issues with their morphological characteristics: they are compact, have a short duration, mono-stem structure, are shorter than traditional varieties, exhibit synchronized maturity and are highly adaptable to HDPS. These traits make compact cotton more suitable for mechanized harvesting (11,12). Spacing is crucial in efficiently utilizing available resources among the various production factors. Determining the optimal plant spacing is essential for maximizing the use of light, soil moisture and CO_2, thereby enhancing crop yield. While a closer planting strategy may produce fewer bolls than cotton planted conventionally, it keeps a larger proportion of all bolls in the first sympodial position and fewer in the second position (13). The benefits of ultra-narrow row planting include improved light interception, an enhanced LAI and increased early competitiveness (14).

Cotton growth and development are significantly influenced by both environmental conditions and agronomic practices (15). Nutrient management is a critical practice for achieving the highest seed cotton yields. Nutrient management in compact cotton is particularly complex due to the simultaneous production of vegetative and reproductive structures during the active growth phase (16). The levels of NPK greatly influence cotton's growth and development, ultimately enhancing yield attributes, overall yield and fiber quality (17). Cotton production requires a selection of strategies, such as maintaining a sufficient plant density, applying the right amount of fertilizer, utilizing growth regulators, etc. Among these, plant spacing (density) and nutrient management are crucial factors that influence seed cotton's growth and yield. With all the above information, the present study was designed to evaluate the effect of nutrients and spacing on growth characters, yield attributes and yield under HDPS of cotton.

Materials and Methods

Experimental site

The experiments were conducted in two locations to study yield maximization through agronomic strategies under a high-density cotton planting system. The first field experiment was conducted at a farmer’s field in Madathanoor village, Pochamapalli taluk, Krishnagiri district, at 12°32’3” N latitude and 78°38’4” E longitude, with an altitude of 353 m above mean sea level (MSL), during August to January 2023-2024. The second field experiment was carried out at the GL-4 block of Annamalai University Experimental Farm, Annamalai Nagar, located at 11°24’ N latitude and 79°72’ E longitude, with an altitude of 5.79 m above MSL, from January to June 2024. The soil at the farmer’s field was sandy clay loam, whereas the experimental farm had clay loam soil, with pH values of 8.2 and 7.7, respectively. The available NPK content in the farmer’s field were 236 kg ha^{-1}, 15.50 kg ha^{-1} and 311 kg ha^{-1}, respectively, while at the experimental farm, these values were 234 kg ha^{-1}, 20.78 kg ha^{-1} and 309 kg ha^{-1}, respectively.

Weather and climate

The climate of Madathanoor is moderately warm month, with august to october. The mean maximum temperature fluctuates between 31.8˚C to 26.8˚C with a mean of 29.3˚C. The weekly minimum mean temperature ranges from 21.7˚C to 17.5˚C with a mean of 19.6˚C. The mean relative humidity is 74 percent. The crop received rainfall of 97.3 mm distributed over 17 rainy days. The climate of Annamalai Nagar is moderately warm, with hot summer months. The mean maximum temperature fluctuates between 39.5˚C to 30.4˚C, with a mean of 34.95˚C, while the minimum temperature ranges from 23.9˚C to 17.6˚C, with a mean of

20.75°C. The mean relative humidity is 70.35 percent and the crop received rainfall of 55.4 mm, which was distributed over 6 rainy days.

Experimental design and treatments

The field experiment was laid out in a factorial randomized block design with three replications. The experiment comprised twelve treatment combinations containing three levels of nutrients and four levels of spacing. The treatments were allocated randomly at each replication to reduce the experimental error**.** The detailed experimental design along with nutrient levels and RDF are elaborated in table 1

Crop management

Cotton variety CO 17 (TCH 1819) was chosen for the study, which is highly suitable for high-density planting due to its compact nature. As per the treatment, fertilizer was applied in the plots before sowing. Full dose of phosphorus (P) and half dose of nitrogen (N) and potassium (K) were applied as basal at the time of sowing. The remaining half of the N and K were top-dressed in two equal splits at 30 and 60 days after sowing (DAS) as per the treatments. The nutrient sources for NPK were urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O), respectively. First irrigation was given immediately after sowing and life irrigation was given on 4 DAS. Subsequent irrigation was given at intervals of 8 to 10 days, depending on the rainfall and soil moisture. Well is the source of irrigation and the open furrow irrigation method was adopted. All recommended agronomic practices and timely need-based plant protection measures were taken to establish healthy crop maintenance.

Data collection

Five sample plants from each treatment (Plot size - 20 m^2) were chosen randomly and labelled for recording various biometric observations at different crop growth stages, such as

Plant height: The plant height was recorded at harvest. The height was measured from the basal point nearer to cotyledonary node to the last opened leaf of the main shoot and expressed in cm.

Dry matter production: The plants selected randomly in border rows were cut close to the cotyledonary node at 30, 60 and 90 DAS and harvested for estimating DMP. The collected samples were chopped, air-dried and then oven-dried at 80°C ±5°C till concordant values were obtained. The dry weight of samples was recorded and expressed in kg ha^{-1}.

Table 1. Representation of nutrient levels and recommended doses of fertilizer

S.No.	Code	Nutrient level	Proportion of NPK (kg ha^{-1})
1.	N_1	100%	80:40:40
2.	N_2	125%	100:50:50
3.	N_3	150%	120:60:60
Recommended doses of fertilizers			
S.No.	**Code**	**Spacing dimension**	
1.	S_1	60 x 10 cm	
2.	S_2	60 x 15 cm	
3.	S_3	70 x 10 cm	
4.	S_4	100 x 10 cm	

Leaf area index: The leaf area was measured on the leaves of the tagged cotton plants at the flowering stage and the LAI was calculated using the following formula (18).

$$LA = L \times W \times CF \times NL \times NP \qquad \text{(Eqn.1)}$$

LA = Leaf area (cm^2)
L = Length of the leaf (cm)
W = Width of the leaf (cm)
CF = Correction factor (0.7)
NL = Number of leaves plant^{-1}
NP = Number of plant unit area^{-1}

$$LAI = \frac{\text{Leaf area}}{\text{Ground area}}$$

Where,

Additional parameters: Number of sympodial branches plant^{-1}, number of squares plant^{-1}, number of bolls plant^{-1}, boll weight (g) and Seed cotton yield were recorded plot-wise. The picked seed cotton was shade dried for 4 hours before weighing it. The total yield was computed and recorded as kg ha^{-1}. The data collected on various characteristics during the field investigations were analyzed statistically according to a standardized method (19).

Statistical analysis

Significant differences among treatments were evaluated using the 'F' test and critical differences were determined at a 5% probability level to draw statistical conclusions. Treatments showing no significant differences were labeled as "NS".

Results

Growth characters

The application of different nutrient levels significantly influenced the plant height. Among the treatments tested, the 150% RDF (N3) application recorded the maximum plant height of 122.43 cm in environment I and 116.26 cm in environment II at harvest, respectively. The lowest plant height was recorded by applying 100% RDF (N_1) in environment I and environment II. Crop spacing significantly increased the plant height in cotton. Spacing of 60 x 10 cm (S_1) recorded a maximum plant height of 120.23 cm in environment I and 114.02 cm in environment II at harvest, respectively. It was followed by the spacing of 75 x 10 cm (S_3). However, the minimum plant height was observed under 100 x10 cm (S4) spacing in environments I and II.

The application of different nutrient levels significantly influenced the LAI in cotton. Among the treatments tested, 150% RDF (N_2) application recorded the maximum LAI of 3.52 in environment I and 3.46 in environment II at the flowering stage. The least LAI was recorded by 100% RDF (N_1) in environment I and environment II. Crop spacing significantly influenced the LAI in cotton. Among the treatments tried, spacing of 100 x10 cm (S_4) recorded a higher LAI of 3.48 in environment I and 3.43 in Environment II at the flowering stage. And it was followed by a spacing of 60 x 15 cm (S_2). However, the least LAI was recorded under the spacing of 60 x 10 cm (S_4) in environment I and Environment II.

The application of different nutrient levels significantly increased the DMP in cotton. The 150% RDF (N3) application recorded the maximum DMP of 5930 kg ha^{-1} in environment I and 5710 kg ha^{-1} in environment II at harvest, respectively. The least DMP was recorded under 100% RDF (N_1) in environments I and II. Crop spacing significantly influenced the DMP in cotton. Spacing of 100 x 10 cm (S_4) recorded a maximum DMP of 5794 kg ha^{-1} in environment I and 5580 kg ha^{-1} in environment II at harvest, respectively. This was followed by a spacing of 60 x 15 cm (S_2). However, the least DMP was recorded under the spacing of 60 x 10 cm (S_1) in environment I and environment II.

Yield attributes

The application of different nutrient levels significantly influenced the sympodial branches plant^{-1} in cotton. Application of 150% RDF (N_3) recorded the maximum number of sympodial branches of 9.17 in environment I and 10.75 in environment II, respectively. The least number of sympodial branches, 6.62 and 7.69, were recorded under 100% RDF (N1) in environments I and II, respectively. Crop geometry significantly influenced the sympodial branches plant^{-1} in cotton. 100 x10 cm (S_4) Spacing recorded the maximum number of sympodial branches of 8.88 and 10.43 in environments I and II, respectively. This was followed by spacing of 60 x 15 cm (S_2). The least number of sympodial branches 6.70 and 7.79, was recorded under 60 x 10 cm (S_1) spacing in environments I and II, respectively.

Nutrient levels significantly influenced the number of squares plant^{-1}. Among the different nutrient levels, 150% RDF (N_3) application recorded the maximum number of squares plant^{-1} of and 36.24 in environment I and 37.94 in environment II, respectively. The least number of squares plant^{-1} of 29.89 and 31.21 was recorded under 100 % RDF (N_1) in environments I and II, respectively. Among the different plant densities, 100 x10 cm (S_4) adoption recorded the maximum number of squares plant-1 of 35.48 and 37.19 in environments I and II, respectively. This was followed by spacing of 60 x 15 cm (S_2). The least squares plant-1 of 30.11 and 31.40 were recorded under spacing of 60 x10 cm (S1) in environments I and II, respectively.

Application of different nutrient levels and crop spacing imposed on cotton significantly impacted the number of bolls plant^{-1}. Among the different nutrient levels, 150% RDF (N_3) applications recorded the maximum number of bolls of 13.77 and 13.00 in environment I and crop II, respectively. The least number of bolls of 10.30 and 10.05 was recorded under 100% RDF (N_1) in environments I and II, respectively. Among the different plant densities tried, spacing of 100 x10 cm (S_4) recorded the maximum number of bolls of 13.40 and 12.67 in environments I and II, respectively. This was followed by spacing of 60 x 15 cm (S_2). The least number of bolls of 10.40 and 10.08 was recorded under 60 x10 cm (S_1) spacing in environment I and environment II, respectively.

The application of different nutrient levels significantly influenced the boll weight in cotton. Applying 150% RDF (N3) recorded the maximum boll weight of 3.30 and 3.32 g in environments I and II, respectively. The lowest boll weight of 3.08 and 3.09 g was recorded under 100% RDF (N_1) in environment I and II, respectively. Crop geometry significantly influenced the boll weight in cotton. Among the treatments tried, spacing of 100 x 10 cm (S_4) recorded the maximum boll weight of 3.28 and 3.30 g in Environment I and Environment II, respectively. This was followed by spacing of 60 x 15 cm (S_2). The least boll weight of 3.08 and 3.10 g was recorded under 60 x10 cm (S1) spacing in environments I and II, respectively.

Yield

The influence of different nutrient levels was favorable with respect to the yield of cotton. Among the different nutrient levels used, 150% RDF (N_3) recorded the maximum seed cotton yield of 2622 and 2508 kg ha^{-1} in environments I and II, respectively. The least seed cotton yield of 2161 and 2048 kg ha^{-1} was recorded under 100% RDF (N_1) in environments I and II, respectively. Among the different spacings imposed, 100 x10 cm (S4) spacing recorded the maximum seed cotton yield of 2570 and 2458 kg ha-^{1} in environments I and II, respectively. This was followed by spacing of 60 x 15 cm (S_2). The least seed cotton yield of 2181 and 2069 kg ha^{-1} was recorded under spacing of 60 x10 cm (S_1) in environments I and II, respectively.

The linear regression analysis showed that seed cotton yield was significantly positively correlated with sympodial branches (R^2 = 1.0 in environment I and environment II, respectively) (Fig. 1 & 2). The R^2 values of the seed cotton yield were 0.98 with the number of bolls per plant in Environment I and Environment II, respectively (Fig. 3 & 4).

Economics

Among the treatments imposed, the application of 150% RDF and spacing of 100 x 10 cm (N_3S_4) recorded a higher net income of Rupees 118365 and 110744 and benefit-cost ratio of Rupees 2.88 and Rupees 2.76 in environment I and crop II, respectively. This was followed by applying 150% RDF and spacing of 60 x 15 cm (N_3S_2), which recorded Rupees 2.78 and Rupees 2.67 in Environment I and Environment II, respectively. The least net income of Rupees 70408 and 62512 and the benefit-cost ratio of rupees 2.17 and 2.03 were recorded under 100% RDF and spacing of 60 x 10 cm (N_1S_1) in environments I and II, respectively.

Discussion

Growth attributes

The various growth characteristics of cotton, such as plant height, LAI and DMP, were significantly influenced by different levels of nutrients and spacing (Table 2). Among the different nutrient levels, the 150 % RDF (N_3) application recorded the maximum plant height, LAI and DMP. This might be due to the greater amounts of the primary nutrients available in the soil solution, which leads to more cell division and elongation (20). Nitrogen is essential for nucleic acid and protein synthesis, which

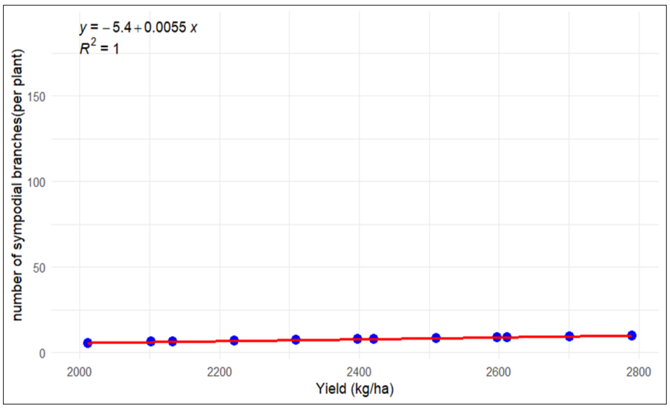

Fig. 1. Regression between seed cotton yield (kg ha^{-1}) and the number of sympodial branches plant^{1} in environment I.

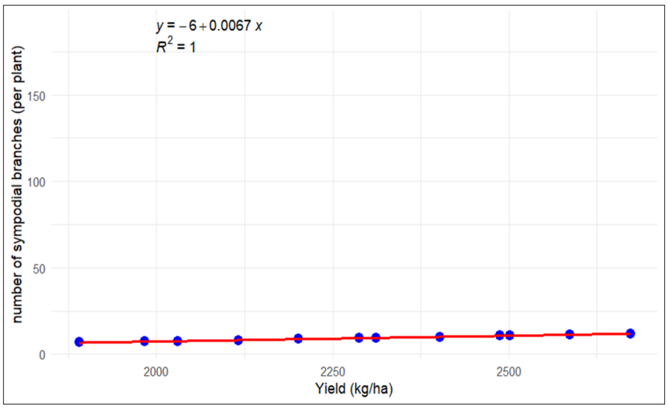

Fig. 2. Regression between seed cotton yield (kg ha^{-1}) and number of sympodial branches plant-1 in environment II.

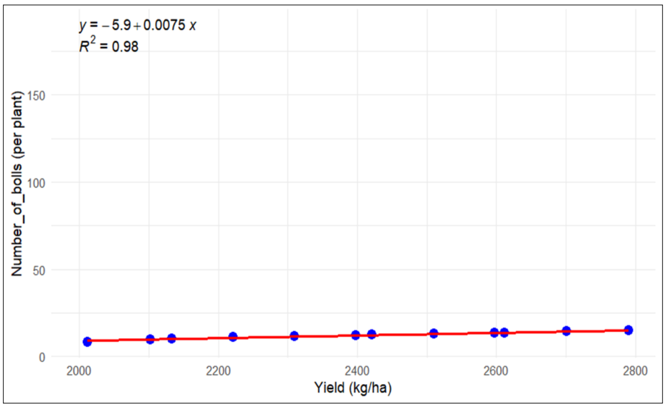

Fig. 3. Regression between seed cotton yield (kg ha^{-1}) and number of bolls plant-1 in environment I.

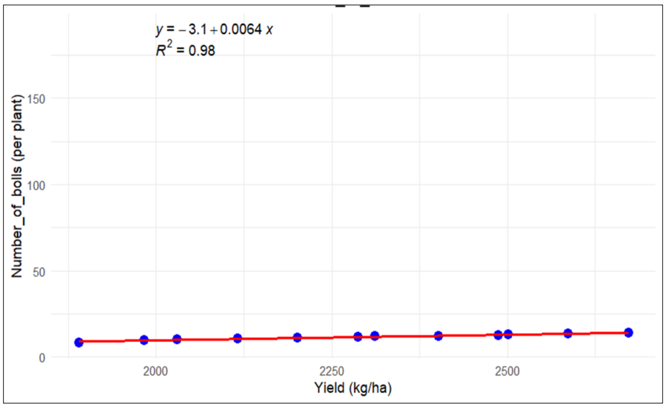

Fig. 4. Regression between seed cotton yield (kg ha^{-1}) and number of bolls plant-1 in environment II.

Table 2. Effect of nutrients and spacing on plant height, dry matter production at harvest stage and leaf area index at flowering stage of cotton

Treatments	Plant height		Leaf area index		Dry matter production	
	Environment I	Environment II	Environment I	Environment II	Environment I	Environment II
Nutrient levels						
N_1	104.64	98.50	3.18	3.14	4612	4479
N_2	113.59	107.42	3.36	3.31	5373	5187
N_3	122.43	116.26	3.52	3.46	5929	5709
S.Ed.	0.98	0.99	0.01	0.01	44.71	44.81
CD (p=0.05)	2.03	2.07	0.03	0.03	93.34	92.94
Spacing						
S_1	120.23	114.02	3.19	3.15	4665.98	4521.87
S_2	111.27	105.16	3.41	3.36	5522.49	5335.54
S_3	115.69	109.48	3.34	3.28	5237.24	5064.15
S_4	107.02	100.92	3.48	3.43	5793.99	5579.94
S.Ed.	1.13	1.15	0.02	0.02	51.71	50.78
CD (p=0.05)	1.13	2.39	0.04	0.04	107.78	105.32

boosts the photosynthetic rate, leaf expansion and leaf persistence. So, LAI is to be sensitive to N availability to crop plants (21). The role of NPK for dry matter accumulation was significant. In contrast, N promotes leaf growth and forms proteins and chlorophyll, P supports root development and K contributes to stem and root growth, which are crucial for photosynthesis (22).

With respect to different spacing, 60 x 10 cm (S_1) recorded the higher plant height in crop I and crop II, respectively. The larger number of plants per unit area produced more height per plant, possibly due to the increased competition for sunlight and CO_2. It might also be due to the closer spacing induced vertical growth due to congestion of plant per unit area. Conversely, plants in wider spacing tended to be slightly shorter due to the greater space availability around each plant, facilitating more sideward growth (23). The spacing of 100 x 10 cm (S_4) recorded the maximum LAI and DMP in Environment I and Environment II, respectively. The LAI is an important parameter in crop growth, reflecting the leafiness and, consequently, the photosynthetic capability of the crop. This could be due to adequate space, moisture and nutrient availability facilitating better leaf growth. This resulted in a greater number of larger leaves, thereby increasing the LAI (24). Higher dry matter accumulation per plant was observed with wider spacing, primarily due to the larger ground area, maximum moisture, more nutrients and more light interception. This resulted in more photosynthetic activity and more biomass accumulation through plant metabolism (25).

Yield attributes

The yield attributes *viz.* number of sympodial branches plant^{-1}, number of squares plant^{-1}, number of bolls plant^{-1} and boll weight were significantly influenced by different levels of RDF application and spacing (Table 3). Among the

Table 3. Effect of nutrients and spacing on yield attributes and seed cotton yield of cotton

Treatments	Sympodial branches plant^{-1}		Number of squares plant^{-1}		Number of bolls plant^{-1}		Boll weight (g)		Seed cotton yield (kg ha^{-1})	
	Environment I	Environment II	Environment I	Environment II	Environment I	Environment II	Environment I	Environment II	Environment I	Environment II
Nutrient levels										
N_1	6.62	7.69	29.89	31.21	10.30	10.05	3.08	3.09	2161	2047
N_2	7.99	9.43	33.26	34.74	12.39	11.76	3.20	3.22	2418	2311
N_3	9.17	10.75	36.24	37.94	13.77	13.00	3.30	3.32	2621	2508
S.Ed.	0.07	0.08	0.28	0.29	0.10	0.19	0.01	0.01	20.93	19.41
CD (p=0.05)	0.14	0.16	0.59	0.62	0.21	0.09	0.02	0.02	42.79	40.60
Spacing										
S_1	6.70	7.79	30.11	31.40	10.40	10.08	3.08	3.10	2181	2069
S_2	8.33	9.80	34.14	35.73	12.80	12.16	3.23	3.25	2477	2368
S_3	7.78	9.15	32.78	34.19	12.02	11.50	3.18	3.20	2373	2261
S_4	8.88	10.43	35.48	37.19	13.40	12.67	3.28	3.30	2570	2458
S.Ed.	0.08	0.09	0.33	0.34	0.12	0.23	0.01	0.01	24.33	22.87
CD (p=0.05)	0.16	0.19	0.68	0.71	0.25	0.10	0.03	0.03	49.87	47.19

nutrient treatments, N_3 (150% RDF) registered the higher number of sympodial branches plant^{-1}, number of squares plant^{-1}, number of bolls plant^{-1} and boll weight in Environment I and crop II, respectively. The increased sympodial branches plant^{-1} might be attributed to the higher nutrient levels, which promote more cell division and elongation, resulting in the maximum number of lateral branches. The high availability of fertilizers favored the synthesis of growth-supporting constituents in the plant system, favoring protein increase, consequently increasing the number of bolls plant^{-1} (26). The rise in cotton's boll weight under higher fertilizer application levels might be due to enhanced availability and uptake of nutrients that lead to enhanced photosynthesis, expansion of leaves and translocation of nutrients to reproductive parts (27).

With respect to spacing treatments, S_4 (100 x 10 cm) registered the number of sympodial branches plant^{-1}, number of squares plant^{-1}, number of bolls plant^{-1} and boll weight in Environment I and Environment II, respectively. The greater space allowed for lateral branch expansion and promoted the development of auxiliary buds, resulting in more branches compared to closer-spaced crops (28). The higher number of bolls in wider-spaced plants could be attributed to the ample space for growth, improved aeration and sufficient sunlight penetration into the canopies. These conditions facilitate the biosynthesis of plant hormones, leading to increased boll retention (29). The 100 x 10 cm spacing provided optimal crop geometry, ensuring a sufficient carbohydrate supply to meet the demands of individual plants, which resulted in higher boll weight (30).

Yield

The seed cotton yield was significantly influenced by different levels of RDF application and spacing (Table 3). Among the different nutrient treatments, N_3 (150% RDF) registered the maximum seed cotton yield in environments I and II. The seed cotton yield could be higher due to relatively higher biomass, better photo-assimilation partitioning towards reproductive structures, higher values of yield components, chlorophyll content and other growth parameters (26). Among the treatments involving different spacing, S_4 (100 x 10 cm) recorded the higher seed cotton in Environment I and Environment II. This could be due to better aeration and lesser inter-plant competition for nutrients and moisture that induced higher photosynthesis, resulting in higher DMP and efficient DMP partitioning to sink (31). The relationship between seed cotton yield and yield attributing characters were positive.

Economics

Among the treatments imposed, the application of 150% RDF + 100 X 10 cm spacing (N_3S_4) recorded a higher net income of Rupees 118365 and Rupees 110744 ha^{-1} and benefit-cost ratio of Rupees 2.88 and Rupees 2.76 in environments I and II, respectively (Table 4). The enhanced nutrient availability due to increased fertilizer application and optimum plant population improved yield attributing characters and yield. This ultimately led to increased gross income and profitability.

Table 4. Effect of nutrients and spacing on the cost of cultivation, net income and benefit cost ratio of cotton

Treatments	Cost of Cultivation (Rs ha^{-1})	Environment I			Environment II		
		Gross Income (Rs ha^{-1})	Net Income (Rs ha^{-1})	Benefit Cost Ratio (Rs)	Gross Income (Rs ha^{-1})	Net Income (Rs ha^{-1})	Benefit Cost Ratio (Rs)
N_1S_1	60295	130812	70408	2.17	122916	62512	2.03
N_2S_1	61961	138622	76495	2.23	131927	69800	2.12
N_3S_1	63663	155863	92341	2.45	148691	85169	2.34
N_1S_2	59810	144372	84430	2.41	137552	77610	2.29
N_2S_2	61476	163135	101470	2.65	156137	94472	2.53
N_3S_2	63178	175559	112499	2.78	168112	105052	2.67
N_1S_3	60083	136622	76420	2.27	128927	68725	2.14
N_2S_3	61749	157383	95458	2.54	150311	88386	2.43
N_3S_3	63451	168858	105538	2.67	161673	98353	2.55
N_1S_4	59700	150127	90289	2.51	143043	83205	2.39
N_2S_4	61366	169788	108227	2.76	162573	101012	2.64
N_3S_4	63068	181321	118365	2.88	173700	110744	2.76

Conclusion

Cognizing the several parameters in unison on environment I and crop II, the application of graded levels of nutrients and different spacing was highly impressive, which had a remarkable effect on the growth, yield components and seed cotton under a HDPS. Application of 150% RDF at (120:60:60 kg NPK ha^{-1}) was found to be the optimum dose of nutrient and adopting 100 x 10 cm plant spacing (100000 plants ha^{-1}) was found to be the optimum plant population to get higher seed cotton yield under HDPS. In a nutshell, it can be concluded that the application of 150% RDF + 100 x 10 cm spacing (N_3S_4) recorded a higher net income of Rs. 118365 ha^{-1} and Rs. 110744 ha^{-1} and benefit-cost ratio of 2.88 and 2.76 in environments I and II, respectively. Therefore, this practice is an agronomically sound and economically viable technique and 150% RDF + 100 x 10 cm spacing can be recommended for cotton farmers for better yields and returns.

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Authors' contributions

AS participated in composing the original draft. GR designed, reviewed and edited the article. SS, BA, SN, SP and SK contributed to and reviewed the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

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References

1. Kaur S, Singh K, Deol JS, Malik S, Kaur N. Effect of plant growth regulators and defoliants on growth and productivity of American cotton (*Gossypium hirsutum* L.). Agric Res J. 2021;58 (4):650–56. https://doi.org/10.5958/2395-146X.2021.00092.2
2. Kairon MS, Laise DB, Venugopalam MV. Cotton. In: Prasad R, editor. Field Crops Production. New Delhi (IN): ICAR; 2004. p. 646–74.
3. Tariq M, Yasmeen A, Ahmad S, Hussain N, Afzal MN, Hasanuzzaman M. Shedding of fruiting structures in cotton: factors, compensation and prevention. Trop Subtrop Agroecosystems. 2017;20(2):251–62.
4. Constable GA, Bange MP. The yield potential of cotton (*Gossypium hirsutum* L.). Field Crops Res. 2015;182:98–106. https://doi.org/10.1016/j.fcr.2015.07.017
5. Zubair M, Ibrahim S, Atolani O, Hamid A. Chemical composition and nutritional characterization of cotton seed as potential feed supplement. J Turkish Chem Soc Sec A. 2021;8(4):977–82. https://doi.org/ 10.18596/jotcsa. 906949
6. AICCIP. All India coordinated cotton improvement project-Annual Report. Coimbatore (IN): Tamil Nadu Agricultural University; 2016.
7. AICCIP. All India coordinated cotton improvement project-Annual Report. Coimbatore (IN): Tamil Nadu Agricultural University; 2019.
8. OECD-FAO. OECD-FAO Agricultural Outlook 2019-2028 [Internet]. Paris: OECD Publishing; Rome: Food and Agriculture Organization of the United Nations; 2019 [cited 2024 Aug 24].
9. AICRP. ICAR-All India co-ordinated research project on cotton-Annual Report. New Delhi (IN): Indian Council of Agricultural Research; 2023. p. 1–4.
10. Devi P, Singh K, Sewhag M, Kumar S. Performance of Bt cotton evaluated in relation to mulching and weed control measures in Northwest India. J Cotton Res. 2024;7:35. https://doi.org/10.21203/rs.3.rs-3438310/v1
11. Gunasekaran M, Premalatha N, Kumar M, Mahalingam L, Sakthivel N, Senguttuvan K, et al. Cotton CO17-A short-duration, high-yielding compact variety suitable for high-density planting system. Electron J Plant Breed. 2020;11(4):993–1000. https://doi.org/10.37992/2020.1104.162
12. Sudhakar P. Mechanized harvesting in cotton in India– An overview. Asian J Sci Technol. 2013;4(10):145–48.
13. Vories ED, Glover RE. Comparison of growth and yield components of conventional and ultra-narrow row cotton. J Cotton Sci. 2006;10(3):235–43.
14. Wright DL, Marois JJ, Sprenkel RK, Rich JR. Production of ultra narrow row cotton. Gainesville (FL): University of Florida, IFAS Extension; 2011. SSAGR-83.
15. O'Berry NB, Faircloth JC, Jones MA, Herbert DA, Abaye AO, McKemie TE, Brownie C. Differential responses of cotton cultivars when applying mepiquat pentaborate. Agron J. 2009;101(1):25–31. https://doi.org/10.2134/agronj2007.0333
16. Khargharate VK, Ghanbahadur M, Hiwale S, Chirde P. Effect of high-density planting, nutrient management and moisture conservation on economics and nutrient uptake of *hirsutum* cotton under rainfed conditions. J Agric Res Technol. 2019;44 (2):138–45.
17. Shah AN, Iqbal J, Tanveer M, Yang G, Hassan W, Fahad S, et al. Nitrogen fertilization and conservation tillage: a review on growth, yield and greenhouse gas emissions in cotton. Environ Sci Pollut Res. 2017;24:2261–72. https://doi.org/10.1007/s11356-016-7894-4
18. Iruthayaraj MR, Sivaraj A. Estimation of cotton leaf area. Curr Res. 1979;8(5):83–85.
19. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York (US): John Wiley and Sons; 2010. p. 97–107.
20. Malakannavar S, Halepyati AS, Yadahalli GS, Chittapur BM, Narayanrao K, Ambika V. Effect of macronutrient and morphoframe manipulation on growth, yield and economics of Bt cotton (*Gossypium hirsutum* L.). Adv Res. 2018;13(1):1–8. https://doi.org/10.9734/AIR/2018/38557
21. Pyne S, Negi MS, Shukla A, Malik N, Paul J. Effect of NPK nutrition on leaf area index and chlorophyll content of fibre flax (*Linum usitatissimum* L.). Pharma Innov. 2022;11(7):2076–78.
22. Gu Y, Zhang X, Tu S, Lindström K. Soil microbial biomass, crop yields and bacterial community structure as affected by long-term fertilizer treatments under wheat-rice cropping. Eur J Soil Biol. 2009;45(3):239–46. https://doi.org/10.1016/j.ejsobi.2009.02.005
23. Anbarasan S, Ramesh S, Sudhakar P, Kumar BS. Effect of cotton varieties and plant spacing on yield and yield components of compact type cotton under HDPS. J Surv Fish Sci. 2023;10 (1):3968–74. https://doi.org/10.53555/sfs.v10i1.1822
24. Kumar A, Karunakar AP, Nath A. Influences of different planting

density on growth, yield attributes and yields of *hirsutum*, *arboreum* and Bt cotton. Int J Curr Microbiol Appl Sci. 2018;7(6):1872–88. https://doi.org/10.20546/ijcmas.2018.706.223

25. Afzal MN, Tariq M, Ahmad M, Mubeen K, Khan MA, Afzal MU, et al. Dry matter, lint mass and fiber properties of cotton in response to nitrogen application and planting densities. Pak J Agric Res. 2018;32(2):229–40. https://doi.org/10.17582/journal.pjar/2019/32.2.229.240

26. Yadav S, Singh H, Kaur M. Effect of plant spacings and fertilizer levels on growth and productivity of desi cotton (*Gossypium arboreum* L.). Pharma Innov. 2021;10(11):1975–80.

27. Kavya D, Pragathi KCh, Sreenivas G, Ramprakash T, Triveni S. Influence of varied plant densities and nitrogen doses on growth and yield of Bt cotton (*Gossypium hirsutum* L.) under high density planting system. Int J Environ Climate Change. 2022;12(11):1498–504. https://doi.org/10.9734/IJECC/2022/v12i1131131

28. Gouthami R, Nagabhushanam U, Ramanjaneyulu AV, Kamalakar J. Influence of plant geometry and cultivars on growth, yield attributes and yield of HDPS cotton under rainfed shallow soils. Int J Environ Clim Change. 2023;13(10):245–50. https://doi.org/10.9734/ijecc/2023/v13i102702

29. Kumar GT, Medhe NK, Danawale NJ, Bhute NK, Patil MR, Patil VS. Effect of plant density and nitrogen levels on yield and soil by cotton (*Gossypium hirsutum* L.). Biol Forum. 2024;16(5):81–84.

30. 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.

31. Alur A, Halepyati AS, Chittapur BM, Nidagundi JM, Koppalkar BG. Effect of high-density planting and nutrient management on growth and yield of compact cotton (*Gossypium hirsutum* L.) genotypes. J Pharmacogn Phytochem. 2020;9(4):294–97.