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Vaibhav Patil
PG Scholar, Department of Agronomy, Post Graduate Institute, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

AS Latkar
Assistant Professor, Department of Agronomy, Agriculture Research Station, Buldhana, Maharashtra, India

SU Kakade
Professor of Agronomy (CAS), Cotton Research Unit Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

OS Rakhonde
Assistant Professor, Department of Soil Science, Post Graduate Institute, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

AN Paslawar
Ex Professor and Head, Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Corresponding Author:
Vaibhav Patil
PG Scholar, Department of Agronomy, Post Graduate Institute, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India

Standardization of plant geometry of different Bt cotton hybrids for high density planting under drip irrigation

Vaibhav Patil, AS Latkar, SU Kakade, OS Rakhonde and AN Paslawar

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Abstract
A field trial was conducted at Cotton Research Farm, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during the *kharif* season of 2024-25 to evaluate the response of different Bt cotton hybrids under varying plant geometry under drip irrigation. Three Bt hybrids *viz*. AKHH 2022-1 Bt, RCH-971 BG-2 and SWCH 4823 BG-2 with three plant geometry *viz*. 90 cm x 15 cm, 90 cm x 30 cm and 90 cm x 45 cm were laid out in factorial randomized block design with three replications and nine treatment combinations. The field was equipped with an inline drip irrigation system with 16 mm laterals placed at 90 cm apart and drippers spaced 40 cm apart. The results showed that Bt cotton hybrid AKHH 2022-1 Bt recorded significantly higher crop growth, dry matter accumulation, leaf area, chlorophyll content, number of sympodial branches per plant and number of picked bolls per plant compared to other Bt cotton hybrids. AKHH 2022-1 Bt also topped in seed cotton yield (3134 kg ha^{-1}) and lint yield (1165 kg ha^{-1}) significantly over other Bt cotton hybrids. In context to plant geometry Bt hybrids planted at 90 cm x 45 cm provided better crop growth, dry matter accumulation, leaf area, chlorophyll content, number of sympodial branches per plant, number of picked bolls per plant and seed cotton yield per plant compared to plant spacing of 90 cm x 15 cm and 90 cm x 30 cm. However, the denser plant spacing of 90 cm x 15 cm gave significantly highest seed cotton yield (3435 kg ha^{-1}) and lint yield (1260 kg ha^{-1}), which was significantly better than rest of wider spacings. Besides this, AKHH 2022-1 Bt and denser spacing 90 cm x 15 cm registered significantly higher GMR, NMR and B:C ratio. Whereas, in interaction effect AKHH 2022-1 Bt sown at 90 cm x 15 cm closer spacing recorded higher NMR of Rs 145573 and B:C ratio 2.72.

Keywords: Bt cotton hybrids, drip irrigation, economics, plant geometry, yield

Introduction
Cotton (*Gossypium hirsutum* L.) is the most important crop in India and plays a significant role in agriculture and industry worldwide. As per data from the USDA, for the year 2024-25, the expected area under cotton cultivation is 31.1 million hectares and the production is 117.40 million bales, each weighing 217.72 kg. This is an increase of 4.4 lakh bales or 3.89% compared to the previous year estimate. The highest producing countries are China, India, Brazil, the United States, and Pakistan. China is largely producing 28.20 lakh bales, India 25 million bales, Brazil 16.90 million bales, the United States 14.30 million bales, and Pakistan 5.50 million bales. The area under cotton production in China was projected to be 2.85 million hectares in 2023-2024. The first advance estimates indicate that the cotton production is 299.26 lakh bales, which is less than the 325.22 lakh bales in 2023-2024.

Among the states, Maharashtra is the highest producer with 84.80 lakh bales followed by Gujarat (80.01 lakh bales), Telangana (48.95 lakh bales), Rajasthan (20.42 lakh bales) and Karnataka (18.56 lakh bales). As of September 2024, the area under cotton for 2024-25 is 112.94 lakh hectares, which is less than the 123.70 lakh hectares covered in 2023-24. Maharashtra occupied the maximum cotton area with 40.86 lakh hectares, followed by Gujarat (23.66 lakh hectares), Telangana (17.70 lakh hectares), Karnataka (6.84 lakh hectares) and Madhya Pradesh (6.14 lakh hectares).

This experiment was conducted to study the response of different Bt cotton hybrids in different plant geometry on growth, yield attributes, seed cotton yield and fibre quality, nutrients uptake and availability of nutrients at harvest and to study the economics. Bt technology in cotton (2002) could better yield under higher plant densities i.e. high density planting with fewer bolls

per plant, synchronized maturity with uniform bursting through Bt cotton genotypes. Nowadays, there is a stagnation in cotton productivity from the year 2014-15 with cotton productivity of only 439 kg lint ha^{-1} during the year 2023-24 in India. Therefore, there is a need to develop the Bt hybrids suitable for high density planting system for maximization of seed cotton yield. In order to increase the per hectare productivity efforts are being made to develop the hybrids suitable for HDPS. Adoption of HDPS could increase the plant population per hectare which ultimately reflected in increase crop yield. Therefore, it is necessary to standardize the plant geometry for different Bt hybrids. Development of ideal varieties having better adaptation to high density planting with better growth characters and optimum plant population is of paramount importance for this new method of HDPS. Therefore, present investigation was planned and carried out to standardize plant geometry of different Bt cotton hybrids for high density planting under drip irrigation.

Materials and Methods

The field experiment was conducted at the Cotton Research Farm, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during the *kharif* season of 2024-25, to standardize the most suitable plant geometry suitable for different Bt cotton hybrids under high density planting (HDP) with drip irrigation, in order to maximize growth, yield and economic returns. Three Bt hybrids *viz*. AKHH 2022-1 Bt (V_1), RCH-971 BG-2 (V_2) and SWCH 4823 BG-2 (V_3) with three plant geometry *viz*. 90 cm x 15 cm (S_1), 90 cm x 30 cm (S_2) and 90 cm x 45 cm (S_3) were laid out in factorial randomized block design with three replications and nine treatment combinations. The field had a fairly flat and uniform topography. The soil was black and clayey, belonging to vertisols and had a slightly alkaline reaction (pH 8.10) with available nitrogen (214 kg ha^{-1}), medium levels of phosphorus (16.80 kg ha^{-1}), fairly high levels of available potassium (308 kg ha^{-1}) and organic carbon (4.16 g kg^{-1}). The farm used an inline drip irrigation system with 16 mm lateral lines placed at 90 cm intervals and 40 cm dripper spacing. Cotton planting was done on 7th July 2024. Cotton was planted on 7th July 2024. The recommended dose of fertilizer (RDF) (120:60:60 N:P_2O_5:K_2O kg ha^{-1}) was applied through drip fertigation as per the University schedule. Phosphorus was applied as basal, while nitrogen and potassium were supplied in five splits (10% at sowing, 20% at 20 DAS, 25% each at 40 and 60 DAS, and 20% at 80 DAS). The drip system supplied 2.1–3.4 L plant^{-1} day^{-1} depending on crop stage, saving 30–40% water and enhancing fertilizer use efficiency.

Results and Discussion

The results and discussion of the present study have been summarized under following heads:

Effect of Bt hybrids

There were significant differences observed among the Bt cotton hybrids with respect to growth, yield attributes, and seed cotton yield (Table 1). AKHH 2022-1 Bt recorded the tallest plants (127.70 cm), maximum leaf area (36.94 dm^2), higher chlorophyll content (28.10), and total dry matter accumulation (237.96 g plant^{-1}), which were significantly superior over the other two hybrids. The superior performance of AKHH 2022-1 Bt could be attributed to its robust genetic potential and better adaptability under drip irrigation and high-density planting system. Similar results were reported by Venugopalan *et al*. (2011) [14]. Similarly, it produced higher number of sympodial branches (23.89 plant^{-1}) and picked bolls (22.83 plant^{-1}), which ultimately resulted in the maximum seed cotton yield, where Bt cotton hybrid AKHH 2022-1 Bt recorded significantly recorded the highest seed cotton yield (3134 kg ha^{-1}), which was significantly superior to the other two hybrids. This was followed by RCH-971 BG-2 (2928 kg ha^{-1}), while the lowest seed cotton yield was noted with SWCH 4823 BG-2 (2787 kg ha^{-1}). The higher productivity of AKHH 2022-1 Bt could be attributed to its greater plant vigour, higher number of sympodial branches and more picked bolls plant^{-1}, which ensured higher dry matter partitioning towards economic yield. Similar results were reported by Singh *et al*. (2010) [10], Parlawar *et al.* (2017) [8] and Parihar *et al.* (2018) [7].

The hybrid SWCH 4823 BG-2 exhibited the lowest growth and yield performance, with significantly reduced plant height (119.27 cm), sympodial branches (20.11 plant^{-1}), and seed cotton yield (55.70 g plant^{-1}).

Effect of Plant geometry: Among different plant geometry, the highest plant height (127.25 cm) was found in the high density planting with plant spacing of 90 cm x 15 cm. This was followed by lower plant densities with plant spacing of 90 cm x 30 cm (123.20 cm) and 90 cm x 45 cm (117.45 cm). The highest plant height in high density planting was due to more competition between plants. Similar results were reported by Sowmiya and Sakthivel (2018) [12].

Table 1: Growth characters and yield attributes of *Bt* cotton as influenced by different Bt hybrids and plant geometry under drip irrigation.

Treatments	Plant height (cm)	Leaf area (dm^2)	Chlorophyll content (SPAD)	Total dry matter accumulation plant^{-1} (g)	Number of sympodial branches plant^{-1}	Number of picked bolls plant^{-1}
A) Bt hybrids						
V_1-AKHH 2022-1 Bt	127.70	36.94	28.10	237.96	23.89	22.83
V_2-RCH-971 BG-2	120.93	31.42	27.79	234.17	22.23	20.97
V_3-SWCH 4823 BG-2	119.27	30.23	25.71	216.72	20.11	20.73
SE (m) ±	1.13	0.83	0.59	1.05	0.20	0.20
CD at 5%	3.39	2.50	1.76	3.16	0.59	0.60
B) Plant geometry						
S_1-90 cm x 15 cm	127.25	24.26	26.03	220.09	20.78	19.41
S_2-90 cm x 30 cm	123.20	31.22	26.89	227.60	21.63	20.07
S_3-90 cm x 45 cm	117.45	43.10	28.68	241.16	23.82	25.04
SE (m) ±	1.13	0.83	0.59	1.05	0.20	0.20
CD at 5%	3.39	2.50	1.76	3.16	0.59	0.60
Interaction (V x S)						
SE (m) ±	1.96	1.44	1.01	1.82	0.34	0.35
CD at 5%	NS	NS	NS	NS	NS	NS

The maximum leaf area (43.10 dm²), highest chlorophyll content (28.68) and the highest dry matter accumulation per plant (241.16 g) were recorded in the wider plant spacing of 90 cm x 45 cm compared to the narrower plant spacing of 90 cm x 30 cm (227.60 g) and 90 cm x 15 cm (220.09 g). The best accumulation of dry matter and proper distribution of nutrients to the growing parts helped the crop reach its maximum yield potential. Similar results were reported by Manjunatha *et al*. (2010) [6], Kumar and Ramchandra (2019) [4].

The yield attributes characters, such as number of picked bolls per plant (25.04) and seed cotton yield per plant (67.49), were found highest in the wider spacing of 90 cm x 45 cm compared to the closer spacing. Similar results were reported by Reddy and Kumar (2010) [9] and Bhalerao and Gaikwad (2010) [1]. However, the lowest number of bolls per plant in closer spacing was made up for by having more plants per hectare, which led to a significantly higher total seed cotton yield (3435 kg ha^{-1}) in the closer plant spacing of 90 cm x 15 cm compared to wider spacing of 90 cm x 30 cm (2899 kg ha^{-1}) and 90 cm x 45 cm (2514 kg ha^{-1}). Similar results were found by Solanki *et al*. (2020) [11] and Gouthami *et al*. (2023) [2].

Table 2: Seed cotton yield (kg ha^{-1}) as influenced by interaction between Bt hybrids and plant geometry in cotton

Seed cotton Yield (kg ha^{-1})				
Treatments	**S_1 90 cm x 15 cm**	**S_2 90 cm x 30 cm**	**S_3 90 cm x 45 cm**	**Mean (Bt hybrids)**
V_1-AKHH 2022-1 Bt	3744	3030	2626	3134
V_2-RCH-971 BG-2	3429	2908	2447	2928
V_3-SWCH 4823 BG-2	3132	2758	2470	2787
Mean (Plant geometry)	3435	2899	2514	
SE (m) ±	48			
CD at 5%	143			

Table 3: Lint yield (kg ha^{-1}) as influenced by interaction between Bt hybrids and plant geometry in cotton

Lint yield (kg ha^{-1})				
Treatments	**S_1 90 cm x 15 cm**	**S_2 90 cm x 30 cm**	**S_3 90 cm x 45 cm**	**Mean (Bt hybrids)**
V_1-AKHH 2022-1 Bt	1392	1121	981	1165
V_2-RCH-971 BG-2	1270	1083	912	1088
V_3-SWCH 4823 BG-2	1117	1024	931	1024
Mean (Plant geometry)	1260	1076	941	
SE (m) ±	22			
CD at 5%	66			

Economics

Among the treatments, AKHH 2022-1 Bt recorded the highest Gross Monetary Returns (Rs. 229411 ha^{-1}), Net Monetary Returns (Rs. 145573 ha^{-1}) and Benefit–Cost ratio (2.72). In contrast, the hybrid SWCH 4823 BG-2 registered the lowest Gross Monetary Returns (Rs. 204371 ha^{-1}), Net Monetary Returns (Rs. 122962 ha^{-1}) and Benefit: Cost ratio (2.50).

With respect to plant geometry, closer spacing of 90 cm × 15 cm proved most remunerative by realizing maximum Gross Monetary Returns (Rs. 251311 ha^{-1}), Net Monetary Returns (Rs. 162205 ha^{-1}) and Benefit–Cost ratio (2.82). On the other hand, the wider spacing of 90 cm x 45 cm resulted in the lowest economic returns with Gross Monetary Returns (Rs. 184576 ha^{-1}), Net Monetary Returns (Rs. 107835 ha^{-1}) Benefit–Cost ratio (2.40) and highest seed cotton yield ha^{-1}. Similar results were reported by Kakade *et al*. (2023) [3]. (Table 4).

Table 4: Seed cotton yield (kg ha^{-1}), Lint yield and economics of Bt cotton influenced by different Bt hybrids and plant geometry under drip irrigation.

Treatments	Seed cotton yield (kg ha^{-1})	Lint yield (kg ha^{-1})	GMR (Rs. ha^{-1})	NMR (Rs. ha^{-1})	B:C ratio
A) Bt hybrids					
V_1-AKHH 2022-1 Bt	3134	1165	229411	145573	2.72
V_2-RCH-971 BG-2	2928	1088	214669	132269	2.59
V_3-SWCH 4823 BG-2	2787	1024	204371	122962	2.50
SE (m) ±	28	13	1956	1763	-
CD at 5%	83	38	5864	5286	-
B) Plant geometry					
S_1-90 cm x 15 cm	3435	1260	251311	162205	2.82
S_2-90 cm x 30 cm	2899	1076	212564	130764	2.60
S_3-90 cm x 45 cm	2514	941	184576	107835	2.4
SE (m) ±	28	13	1956	1763	-
CD at 5%	83	38	5864	5286	-
Interaction (V x S)					
SE (m) ±	48	22	3388	3054	-
CD at 5%	143	66	10157	9155	-

Table 5: Net monetary returns as influenced by interaction between Bt hybrids and plant geometry in cotton

Net monetary returns (Rs. ha^{-1})				
Treatments	**S_1 90 cm x 15 cm**	**S_2 90 cm x 30 cm**	**S_3 90 cm x 45 cm**	**Mean (Bt hybrids)**
V_1-AKHH 2022-1 Bt	182106	139421	115193	145573
V_2-RCH-971 BG-2	161663	131636	103508	132269
V_3-SWCH 4823 BG-2	142847	121236	104803	122962
Mean (Plant geometry)	162205	130764	107835	
SE (m) ±	3054			
CD at 5%	9155			

Interaction effect

Treatment combination AKHH 2022-1 Bt and denser spacing 90 cm x 15 cm registered significantly higher seed cotton yield (3744 kg ha^{-1}), lint yield (1392 kg ha^{-1}) and net monetary returns (182106 Rs. ha^{-1}).

Conclusion

The study found that Bt cotton hybrids and plant geometry significantly influenced growth, yield and economics of Bt cotton under high density planting system (HDPS) with drip irrigation. Among the hybrids, AKHH 2022-1 Bt exhibited superior performance in terms of crop growth, yield attributes and seed cotton yield, which resulted in higher GMR, NMR and B:C ratio compared to the other hybrids. Similarly, closer spacing of 90 cm × 15 cm enhanced seed cotton yield on a per hectare basis due to higher plant population, thereby achieving the highest GMR and NMR. The interaction between hybrids and plant geometry was also significant for seed cotton yield, lint yield and economic returns. The combination of AKHH 2022-1 Bt with 90 cm x 15 cm spacing recorded the maximum productivity and profitability, proving its suitability for high density planting systems. Thus, adoption of AKHH 2022-1 Bt at a spacing of 90 cm x 15 cm under drip irrigation is the most effective strategy to maximize yield and economic returns of Bt cotton hybrids and adoption of compact Bt hybrids under high density planting is not only profitable but also regionally suitable, as supported by Latkar *et al.* (2024) [5].

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