



RESEARCH ARTICLE

Effect of fertilizer and growth regulator on yield and yield attributing characters of cotton under high-density planting system

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Abstract

The productivity of cotton is stagnant and high-density planting system (HDPS) is the option for increasing productivity, so currently identifying genotypes in the region suited for HDPS along with canopy management to be tested so that enable to reduce the productivity gaps in the rain fed and irrigated farming as well as the diversified cotton growing areas. The present study was carried out to evaluate the effect of growth retardant and nitrogen levels on plant canopy architecture and enhancing productivity under HDPS. Three nitrogen levels (Recommended dose of nitrogen (RDN), 125 % RDN and 150 % RDN) and 3 levels of growth regulators (No growth regulator, mepiquat chloride (MC) at 20 g/ha at 60 days after sowing (DAS) and MC at 60 & 75 DAS) were studied across two HDPS suited genotypes (GISV-272 and GSHV-180) for three consecutive years (kharif 2019 to 2021). The experiment was laid out in split plot design with three replications at Research Farm of Main Cotton Research Station, Navsari Agricultural University, Surat. The plant height, number of sympodia and mean length of sympodia were significantly influenced due to nitrogen level; while, plant height, mean length of sympodia and plant width were significantly influenced due to genotypes. The growth retardant, MC significantly altered plant height, mean length of sympodia and plant width providing ample space for growth and development to both the genotypes under HDPS. The yield attributing traits and seed cotton yield were influenced greatly by the genotype and nitrogen levels. In this study, GISV 272 and 125 % of recommended nitrogen level under HDPS in rain fed region of Gujarat showed better performance and economics.

Keywords: compact genotype; cotton; growth regulator; high-density planting system; mepiquat chloride; nitrogen

Introduction

Cotton (*Gossypium hirsutum* L.) plays a significant role in the country's economic growth by providing substantial employment and contributing significantly to export earnings. Millions of people are supported directly and indirectly by the farms that grow it, the manufacturing concerns that process it and the domestic and international marketing activities that distribute cotton products. India is the only country where all four cultivated species of cotton are grown on a commercial scale covering a cultivated area of about 130.5 lakh hectares. It ranks second in cotton production with 52 lakh tonnes among all cotton-producing countries following China which accounts more than 20 % of global cotton production (1).

In the global cotton scenario, China has been the leading producer of cotton in recent decades. India was a leader in cotton production for a few years in the last decade. However, China has re-established its position as the leading producer of cotton in the

world since 2018–19. Between 2006 and 2018, the average cotton productivity in the country was above 500 kg/ha, but from 2019 to 2023, productivity slumped, hovering around an average of 440 kg/ha (1). Hence, it is essential to improve productivity of cotton to meet the requirement of cotton globally and efficient use of resources.

Despite the introduction of improved hybrids over the years, we have started witnessing the plateauing of yield levels and decreasing productivity from 2014 to 2024. One alternative option to break this plateau and to increase productivity levels is through exploring compact plant architecture for higher planting densities (2, 3). In high density planting system, plant population per unit increased by narrowing down the row-row and plant-plant spacing. Thus, benefits associated with increased surface residues may also affect fertilizer N application rates for subsequent crops. Greater fertilizer N rates have been suggested for cereal crops residues to offset potential N immobilization because of high nutrient utilization

by high residue producing crops (4). Scientists observed that increased use of N, P and K fertilizers could promote dry matter accumulation in all organs of cotton, significantly increasing seed cotton yield by 9.42–81.71 % (5,6).

However, as planting density increases, individual plants shade each other, decreasing photosynthetic performance due to disturbances in canopy permeability leading to increased square and boll abscission. Adequate growth is beneficial for ventilation and light transmission, as the cotton population adjusts to light interception, the utilization of light energy by leaf area and the absorption of N, P and K nutrients by cotton (7, 8). Reports have shown that the use of density and growth regulators could significantly regulate nutrient uptake and utilization (5, 9).

Plant growth, especially the terminal growth of apical buds, is influenced by the hormone gibberellin. To reduce plant growth, use of gibberellin biosynthesis inhibitor is suggested (10). Mepiquat chloride (MC) is an inhibitor of gibberellin biosynthesis widely utilized for controlling excessive vegetative growth by reducing internode length and, consequently, plant height and leaf area, thus resulting in a more compact plant stature (11–14). Plant growth regulators increase root secretions into the soil and improve the absorption of the cotton root system, hence, promoting the formation of fruiting bodies and larger size. These regulators improve yield and quality by effectively regulating canopy shape, size and mineral nutrient absorption (15–17). In China, Miantaijin is a growth regulator for cotton, containing N,N-dimethylpiperidinium chloride and 2-N,N-diethylaminoethyl caproate, which is widely used. These products regulate the growth, development and promote the transformation of nutrients from source to sink (5, 18–20).

The efficient use of resources, especially of nutrients and other alternatives through sustained releases, lead to research on green synthesis of nano particles or Si and Cu-nanoparticles and using nanoformulations of the products and their applications in seed priming, seed coating and foliar spraying paved ways for sustained releases. The application of nSi reported to enhance the germination in *Vigna unguiculata* (L.) Walp. However, further research studies must be performed to determine the toxic effect of biogenic nSi before mass production and use of agricultural applications (21). The researcher works with the biochar found that biochar adsorbs N₂O molecules, facilitating their delivery to the active site of the enzyme and enhancing the reaction rate. Deeper understandings of molecular interactions open new pathways in developing biochar-based fertilizers with slower, more economically and more environmentally favorable release of nutrients (22).

The high-density planting system (HDPS) in cotton is a highly technical system that requires careful planning, timely planting, vigorous monitoring and prompt interventions. The HDPS leads to excessively tall plants and increased vegetative growth. Therefore, cotton production under HDPS necessitates careful consideration of several management strategies, including the use of plant growth regulators, fertilizers and suitable genotypes (23).

Since cotton exhibits an indeterminate growth habit, vegetative and reproductive growth occur simultaneously for a large part of its life cycle. Nevertheless, sufficient vegetative growth is essential to support reproductive growth. Excessive vegetative growth may be the reason for the higher fruit abortion, delayed crop maturity and consequently delayed harvesting. Most cotton hybrids exhibit aggressive vegetative growth patterns with high nutrient availability

and adequate rainfall or irrigation at the required stages. Uncontrolled vegetative growth can cause fruit and square dropping, delayed maturity and boll rot, ultimately reducing yield (24).

The cotton productivity in Gujarat and in India is stagnant and HDPS is the option for increasing productivity so currently identifying genotypes in the region suited for HDPS along with canopy management to be tested so that decreased the gap in the rain fed and irrigated farming. Hence, an experiment was conducted to evaluate the influence of plant growth regulators and fertilizer levels on cotton under a high-density planting system.

Materials and Methods

Experimental site

The experiment was conducted at the Main Cotton Research Station, Navsari Agricultural University, Surat. The experimental site lies at a cross point of 21°10'16.302" N and 72°48'1.0974" E at an elevation of 11.34 m above the mean sea level. Soil is well-drained clayey, typical black cotton soil having predominant montmorillonite clay minerals by its origin and is medium in fertility.

Experimental details

The treatment details are as below for this experiment.

Main treatment: (N) Three nitrogen level - N1: 100 % RDN, N2:125 % RDN, N3:150 % RDN

Sub treatment-1: (V) Compact genotypes - V1: GISV-272, V2: GSHV-180

Sub treatment-2: (G) Growth regulators - G1: Control, G2: Mepiquat chloride spray at rate of 20 g.ai ha⁻¹ at 60 DAS, G3: Mepiquat chloride spray at rate of 20 g.ai ha⁻¹ at 60 DAS and 75 DAS

The experiment was laid out as per the Split Plot Design. The crop was sown as eighteen treatment combinations in 4.8 m × 7.2 m plot with 3 replicates. The plant spacing under high density was kept at 60 × 15 cm to accommodate 111111 plants/ha instead of normal sowing at 120 × 45 cm accommodating 18518 plants/ha. The plants were sown on receiving at least 80 mm of rain with onset of the monsoon.

Crop management

Cotton seeds of both the promising genotypes for HDPS (GISV-272 and GSHV-180) were collected from Main Cotton Research Station, Navsari Agricultural University, Surat. Seeds were sown on the ridges at 10 kg/ha for HDPS experiment at the commencement of the monsoon. The recommended nitrogen dose for normal sowing was 225 kg N/ha. In the tested treatments of RDN, 125 % RDN and 150 % RDN, nitrogen was applied in 5 equal splits at 30, 60, 75, 90 and 105 days after sowing. The weeds were managed through spraying pre-emergence herbicide, Pendimethalin 30 % EC at 3.0 l/ha, followed by 2F intercultural operations (hoeing) and 2 hand weeding through laborers were carried out. Sucking pests were managed through ETL based sprayings of Imidacloprid 17.8 % SL at 40 mL (Thrips & Leafhopper), Fipronil 5 % SC at 30 mL (leafhopper) and Acephate 75 % SP at 20 g (whitefly) per 10 L of water. For bollworms, one spray of Profenofos 50 EC at 20 mL per 10 L of the water. These broad-spectrum pesticides were selected based on their modes of action and the principles of group rotation to prevent the development of resistance. Mepiquat chloride was used as 5 % aqueous solution procured from Gharada Chemicals Ltd. Nitrogen

fertilizer used as neem coated urea sourced from KRIBHCO, Surat.

The growth and yield attributing traits were recorded from each plot on 5 randomly selected plants. Observations for the plant height, number of sympodia, mean length of sympodia, number of monopodia and shoot to root ratio were taken from 5 randomly selected plants from each plot as per the standard protocol adopted from AICRP on Cotton project. The leaf area index (LAI) for each treatment was worked out using the following formula (25).

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Ground area}} \times 100$$

The boll weight was calculated as an average weight of destructive sampling of 50 bolls. The number of bolls was taken per square meter. The seed cotton yield per hectare was estimated based on the yield from the net plot. The statistical analysis was carried out using the standards SPSS program.

Results and Discussion

Effect on plant height and monopodia

The statistically analyzed data for plant height and monopodia were presented in Table 1. The plant height is significantly affected every year and pooled analysis due to nitrogen doses. Significant higher plant height was observed in treatment 150 % recommended dose of fertilizer (RDF), which was at par with treatment 125 % RDF. As higher fertilizer promotes the growth of plants the plant height showed higher in 150 % RDF fertilizer. Similar results were stated by two groups of scientists in cotton, as plants attain higher height as the nitrogen level increases. These are due to nitrogen stimulating luxuriant growth and especially where cotton, is sensitive crop to

nitrogen (26–28). However, genotypes were non-significant for plant height during 2020–21 and 2021–22 as well as pooled analysis. The MC significantly affected the plant height in pooled and during 2019–20 and 2021–22. The significant lower plant height was observed when plant is treated with mepiquat chloride at rate of 20 g.ai ha⁻¹ at 60 DAS and 75 DAS, which was followed by MC spray at rate of 20 g.ai ha⁻¹ at 60 DAS. The MC is a gibberellic acid inhibitor and hence reduce the height of cotton plant. The application of MC results in a decrease in plant height (14, 29–30).

The number of monopodia is the non-fruiting branch of cotton. The monopodia showed non-significant effect for nitrogen and MC in pooled however genotype showed significant deviation. The non-significant influence of MC on monopodial branches was also observed by previous researchers (29, 31). It may be due to monopodial branches growing out in early-stage crop growth hence not affected by the MC. The genotype GSHV-180 showed significantly higher monopodia as compared to GISV-272, however it is under limit for mechanical picking, as it was below 0.5 per plant. This difference may be attributed to the genetic makeup of variety.

Effect on sympodia

The data for number of sympodia and length of sympodia were presented in Table 2. The number of sympodia was non-significant for all the year and pooled analysis for all treatment except due to nitrogen level in kharif-19. However, Length of sympodia was significantly affected due to nitrogen levels. The increase in nitrogen does lead to increase in the length of sympodia. The nitrogen has positive relation with the length of sympodia. The positive relation of nitrogen application and length of sympodia also observed in previous study (27). This may be due to the sufficient nitrogen level and adequate light resources lead to luxuriant growth of plants. The spray of MC showed significant effect on length of sympodia in

Table 1. Effect of nitrogen and growth regulators on plant height and number of monopodia of cotton genotypes

Treatment	Plant height (cm) at harvest				No of monopodia			
	2019–20	2020–21	2021–22	Pooled	2019–20	2020–21	2021–22	Pooled
N-Nitrogen Level								
N1: 100 % RDN	91.9	146.3	136.8	125.0	0.78	1.04	0.98	0.93
N2: 125 % RDN	108.3	156.4	143.4	136.0	0.78	1.08	0.87	0.91
N3: 150 % RDN	102.8	157.9	150.8	137.2	0.80	1.08	1.03	0.97
S.Em. ±	1.48	1.19	2.12	1.96	0.02	0.07	0.02	0.03
C.D. at 5 %	5.81	4.67	8.03	7.71	NS	NS	0.08	NS
V- Compact genotype								
V1: GISV-272	103.8	153.1	144.7	133.9	0.74	0.96	0.87	0.86
V2: GSHV-180	98.3	154.0	142.7	131.7	0.84	1.17	1.05	1.02
S.Em. ±	1.33	2.37	1.44	0.81	0.03	0.05	0.02	0.02
C.D. at 5 %	3.8	NS	NS	NS	0.09	0.13	0.07	0.06
G- Growth Regulator								
G1: Control	107.9	156.2	157.9	140.7	0.81	0.98	0.92	0.91
G2: MC at 20 g at 60 DAS	99.7	153.5	140.1	131.1	0.78	1.08	0.90	0.92
G3: MC at 20 g at 60 & 75 DAS	95.5	151.0	133.0	126.5	0.77	1.13	1.06	0.99
S.Em. ±	1.62	1.68	1.77	1.69	0.04	0.06	0.03	0.03
C.D. at 5 %	4.70	NS	5.1	4.77	NS	NS	0.09	NS
Interaction Effect								
NV				NS				NS
NG				NS				NS
VG				NS				NS
NVG				NS				NS
YNV				NS				NS
YNG				8.3				NS
YVG				6.7				NS
YNVG				11.7				NS
CV %				5.4				19.71

Number of monopodia value are sinarc transformed and analysed (RDN-Recommended dose of nitrogen, MC-Mepiquat chloride, DAS-days after sowing).

Table 2. Effect of nitrogen and growth regulators on sympodia of cotton genotypes

Treatment	No. of sympodia				Length of sympodia (cm)			
	2019-20	2020-21	2021-22	Pooled	2019-20	2020-21	2021-22	Pooled
N-Nitrogen Level								
N1: 100 % RDN	16.6	21.1	20.4	19.4	24.36	28.72	32.67	28.58
N2: 125 % RDN	19.1	21.3	21.2	20.5	26.47	30.03	34.72	30.41
N3: 150 % RDN	18.6	20.1	22.3	20.3	27.78	32.72	37.52	32.67
S.Em. ±	0.3	0.45	0.4	0.58	0.37	0.39	0.58	0.27
C.D. at 5 %	1.17	NS	NS	NS	1.45	1.53	2.28	0.81
V- Compact Genotype								
V1: GISV-272	18.0	20.5	22.0	20.2	27.28	31.28	33.70	30.75
V2: GSHV-180	18.2	21.1	20.7	20.0	25.13	29.70	36.23	30.36
S.Em. ±	0.5	0.48	0.49	0.29	0.70	0.41	0.89	1.04
C.D. at 5 %	NS	NS	NS	NS	2.02	1.18	NS	NS
G- Growth Regulator								
G1: Control	18.2	21.4	22.0	20.5	28.44	30.47	36.57	31.83
G2: MC at 20 g at 60 DAS	18.3	20.1	20.3	19.6	25.69	31.11	33.30	30.03
G3: MC at 20 g at 60 & 75 DAS	17.9	21.0	21.6	20.2	24.47	29.89	35.04	29.80
S.Em. ±	0.62	0.59	0.6	0.35	0.86	0.50	1.09	0.51
C.D. at 5 %	NS	NS	NS	NS	2.48	1.45	NS	1.43
Interaction Effect								
NV				NS				1.98
NG				NS				NS
VG				NS				2.04
NVG				NS				NS
YNV				NS				NS
YNG				NS				NS
YVG				NS				NS
YNVG				NS				6.04
CV %				12.8				11.85

RDN-Recommended dose of nitrogen, MC-Mepiquat chloride, DAS-Days after sowing.

pooled analysis. The spray of MC significantly reduced the length of sympodia as compared to the control. The length of sympodia decreased as the number of sprays increased. The interaction was significant for the MC and genotypes as well as nitrogen and genotypes in pool analysis. It showed that genotypes have different potential for nitrogen and MC metabolism with respect to length of sympodia. The genotype showed non-significant deviation in pooled analysis. A higher sympodial length was observed when higher nitrogen was applied while MC application significantly reduced sympodial length. Researchers reviewed similar results and stated that the canopy structure becomes more compact due to the application of MC (13). However, other group also found that the sympodial branches and sympodial length increased in Bt hybrid cotton when MC is applied (29). Gibberellin acid and auxin are primarily required for cell elongation and number of cells, the restriction in production of these growth hormones through application of MC lead to reduce the length of sympodia. These also showed that opposite effect of nitrogen and MC for sympodial length. Hence, this combination of treatment might be useful for diversion of nutrients towards the reproductive part instead of the vegetative parts of the cotton plant. This finding was supported by our observation on nitrogen level increase the number of bolls and application of MC showed increased in boll weight. The reduction in sympodial length by the MC makes plant more suitable for the mechanization.

Effect on shoot to root ratio and leaf area index (LAI)

Shoot to root ratio was found not significant due to nitrogen application in individual year however it was significantly influenced due to nitrogen levels and genotypes. The growth regulator showed significant effect on shoot to root ratio in individual year as well as in pooled. The result indicated that higher nitrogen doses lead to lower shoot to root ratio. Whereas water and nitrogen applications have

influenced root to shoot ratio affecting root growth and its distribution. Previous researchers found that H20W75N1 increased root diameter resulted in the development of effective roots (diameter less than 0.05 mm) to efficiently uptake and transport. These changes protect the integrity of the lipid membrane in the root and enhanced root stress tolerance in the 0–80 cm soil layers at 82 and 102 DAE in their experiment. A possible reason was that H20W75N1 increased the available water and nitrogen in the soil layer, while higher available water and nitrogen also promoted the nitrogen reductase content and the root protective enzyme and hence more efficient water and N uptake (32). Likewise, MC also reduced the shoot: root ratio, which indicates that root length was less effected due to MC as compared to plant height. The MC downregulates GhEXP and GhXTH2 and ultimately inhibits internode elongation and ultimately shoot length (33). Among the genotype GSHV-180 showed significant higher shoot: root ratio. The interaction was significant among all three variables that indicates that the effect of level of nitrogen and MC on genotypes was interdependent (Table 3). Mainly, shoot length is reduced significantly when plants treated with the MC which gives the plant architecture suitable for the machine picking, provided appropriate timing of application.

Leaf area index was significantly influenced due to nitrogen levels. The higher nitrogen dose significantly increased the LAI indicating that nitrogen promotes growth of cotton plant. The MC spray significantly affected LAI in individual years as well as in pooled (Table 3). The spray of MC has a significant effect on LAI. The single spray did not show much influence; however, two sprays of MC at 60 DAS and 75 DAS significantly reduced LAI. Previous reports stated that the foliar application of MC in cotton plants gave rise to arrested leaf growth and decreased leaf area with considerably lower levels of GA4 (34), which is in line with our outcomes. Treatment, which

Table 3. Effect of nitrogen and growth regulators on shoot: root ratio and leaf area index of cotton genotypes

Treatment	Shoot: Root ratio				LAI			
	2019-20	2020-21	2021-22	Pooled	2019-20	2020-21	2021-22	Pooled
N-Nitrogen Level								
N1: 100 % RDN	4.05	5.10	5.97	5.04	5.42	5.68	5.86	5.65
N2: 125 % RDN	4.44	5.21	5.91	5.19	5.90	6.08	6.68	6.22
N3: 150 % RDN	3.60	5.19	5.45	4.74	6.26	6.04	7.23	6.51
S.Em.±	0.10	0.04	0.19	0.09	0.11	0.13	0.13	0.15
C.D. at 5 %	0.39	NS	NS	0.28	0.47	NS	0.52	0.58
V- Compact genotype								
V1: GISV-272	3.95	5.15	5.56	4.89	5.44	5.76	5.99	5.73
V2: GSHV-180	4.11	5.18	6.00	5.09	6.28	6.11	7.20	6.53
S.Em.±	0.08	0.03	0.12	0.05	0.06	0.12	0.07	0.18
C.D. at 5 %	NS	NS	0.34	0.14	0.18	0.35	0.19	NS
G- Growth regulator								
G1: Control	4.23	5.18	6.11	5.17	5.97	5.85	6.73	6.19
G2: MC at 20 g at 60 DAS	4.01	5.16	5.59	4.92	5.92	6.03	6.67	6.21
G3: MC at 20 g at 60 & 75 DAS	3.85	5.15	5.63	4.87	5.70	5.91	6.37	5.99
S.Em. ±	0.97	0.03	0.14	0.06	0.07	0.15	0.08	0.06
C.D. at 5 %	0.28	NS	0.41	0.17	0.22	NS	0.23	0.17
Interaction effect								
NV				NS				0.25
NG				NS				NS
VG				NS				NS
NVG				0.41				NS
YNV				NS				NS
YNG				NS				NS
YVG				NS				NS
YNVG				NS				NS
CV %				8.66				7.39

RDN-Recommended dose of nitrogen, MC-Mepiquat chloride, DAS-Days after sowing.

included MC, potassium nitrate (KNO_3), Naphthalene acetic acid (NAA), calcium borate ($Ca_3(BO_3)_2$) and defoliant, achieved a satisfactory LAI, fewer functional leaves and ideal plant height. This balanced growth pattern makes the plants more suitable for mechanical harvesting (35), indicating that more than one growth regulator is required for canopy management in mechanical picking of cotton. The interaction of nitrogen levels and genotypes showed a significant effect, showing that nitrogen response varied with genotypes for LAI (Table 3). The MC downregulates the gene required for biosynthesis of gibberellin, which is required for cell growth and development, leading to lower cell expansion and decreasing LAI. This also aided shredding of leaves by the defoliant for mechanical harvesting/pickings.

Effect on boll weight and number of bolls

Boll weight was non-significant for nitrogen levels however the increase in nitrogen levels numerically increased boll weight. It revealed that beyond a critical level, increase in nitrogen dose did not increase in boll weight. The scientist showed significantly higher boll weight when 125 % nitrogen was applied as compared to 100 % and 75 % (27). The 20 % reduction in Nitrate did not decrease boll weight under high density but decreased it by 3.2 % under low density (36). Hence, optimum nitrogen leads to higher boll weight. The genotypes were significantly affected for boll weight for individual year as well as pooled. GISV 272 showed significantly higher boll weight than GSHV-180. Difference in boll weight among the variety is due to the difference genetic material of genotypes. The MC spray showed a significant effect on boll weight. Boll weight was shown significantly higher due to MC spray as compared to control (Table 4). Similar results were obtained in earlier reports (29). These

may clearly indicate that the nutrients and photosynthate are diverted from the vegetative growth like plant height, length of sympodia and leaf area to reproductive parts of the plant leading to more boll setting and retention and ultimately the weight of bolls.

The number of bolls per square meter was recorded and presented in Table 4. The pooled analysis showed that nitrogen level showed significant effect on number of bolls. The result revealed that number of bolls was significantly higher when 150 % RDN was applied, which was followed by 125 % RDN. The researchers recorded significantly higher number of bolls when 125 % and 100 % nitrogen were given as compared to 75 % nitrogen this might be attributed to nitrogen fertilizer because the cotton plant is especially vulnerable to nitrogen absorption (27). Likewise, the maximum number of bolls may be attributable to enhanced photosynthate assimilation and translocation. These findings were comparable to earlier reports (37). The genotypes exhibited significant variation for number of bolls per square meter. The GSHV-180 showed significantly higher number of bolls as compared to GISV 272. The spray of MC non significantly affected the number of bolls. However, numerically reduction in boll per square meter was observed. The number of bolls was significantly reduced when 0.015 % MC sprayed at square formation and boll development stage (38). The interaction for all 3 variables showed significant effect, which revealed that the effect of nitrogen level and MC varied with the genotype. Significantly higher number of boll in cotton treated with MC was reported earlier (29). Previous reports states that MC application reduced the number of bolls under drought conditions and stated that the effect of MC is variable due difference in environment condition (34).

Table 4. Effect of nitrogen and growth regulators on boll weight and number of bolls of cotton genotypes

Treatment	Boll weight (g)				No. of bolls per sqm			
	2019–20	2020–21	2021–22	Pooled	2019–20	2020–21	2021–22	Pooled
N-Nitrogen Level								
N1: 100 % RDN	3.03	2.51	2.84	2.80	122.6	215.0	150.8	162.8
N2: 125 % RDN	3.02	2.64	2.94	2.87	139.7	232.6	144.1	172.1
N3: 150 % RDN	3.08	2.66	2.92	2.89	143.8	223.0	164.6	177.1
S.Em. ±	0.08	0.07	0.05	0.04	4.94	7.03	3.76	3.71
C.D. at 5 %	NS	NS	NS	NS	15.9	NS	14.7	11.1
V- Compact genotype								
V1: GISV-272	3.53	2.84	3.35	3.24	124.1	210.9	153.0	162.7
V2: GSHV-180	2.56	2.37	2.46	2.46	146.6	236.1	153.3	178.7
S.Em. ±	0.07	0.06	0.07	0.11	4.58	3.47	6.71	3.03
C.D. at 5 %	0.19	0.17	0.20	0.67	13.3	10.0	NS	8.53
G- Growth Regulator								
G1: Control	2.94	2.49	2.80	2.74	140.7	232.5	151.4	174.9
G2: MC at 20 g at 60 DAS	3.12	2.64	3.06	2.94	126.5	224.4	148.8	166.6
G3: MC at 20 g at 60 & 75 DAS	3.08	2.69	2.84	2.87	138.8	213.6	159.3	170.6
S.Em. ±	0.08	0.07	0.08	0.05	5.61	4.25	8.22	3.66
C.D. at 5 %	NS	NS	NS	0.13	NS	12.3	NS	NS
Interaction Effect								
NV				NS				NS
NG				NS				NS
VG				NS				NS
NVG				NS				25.7
YNV				NS				NS
YNG				NS				NS
YVG				NS				NS
YNVG				NS				NS
CV %				11.9				15.6

RDN-Recommended dose of nitrogen, MC-Mepiquat chloride, DAS-Days after sowing.

Effect on seed cotton yield and benefit-cost ratio (BCR)

The seed cotton yield was significantly influenced due to nitrogen levels. The higher the nitrogen level (150 % RDN) showed significantly higher seed cotton yield which was at par with 125 % RDN. The result showed that nitrogen is essential for the higher yield in HDPS cotton. However, the increase was at par with higher dose hence, 125 % RDN is recommended for the HDPS cotton, these also favor BCR which was at par for the 125 % and 150 % RDN (Table 5). The research showed that yield attributing characters along with seed cotton yield is increased with increased nitrogen level to the critical level (27, 39, 40). The genotypes showed significant deviation in seed cotton yield. The significant higher seed cotton yield was observed for the genotype GISV-272 as compared to GSHV-180. The MC were non-significant for seed cotton yield in every year as well as pool analysis. It may be useful for the management of the growth of cotton plants, but we have not observed any impact on seed cotton yield in this experiment (Fig. 1). Benefit-cost ratio also unfavorable to use the MC for seed cotton yield in every environmental condition, however for mechanical picking suitable plant canopy and architecture of plant can be made by using the MC. Significantly higher seed cotton yield was obtained in cotton treated with MC (29). Mepiquat chloride applications reduced plant canopy with variable yield responses (13). Yield responses to MC spray are influenced by several factors, including application rate, plant stage, genotype, site-specific conditions and variable climatic conditions (41). The interaction of plant density and nitrogen level was non-significant for lint mass and fiber quality. Low-dose nitrogen resulted in maximum agronomic and economic nutrient use efficiency and partial factor productivity (PFP). However, the percent relative yield (PRY) at 50 kg

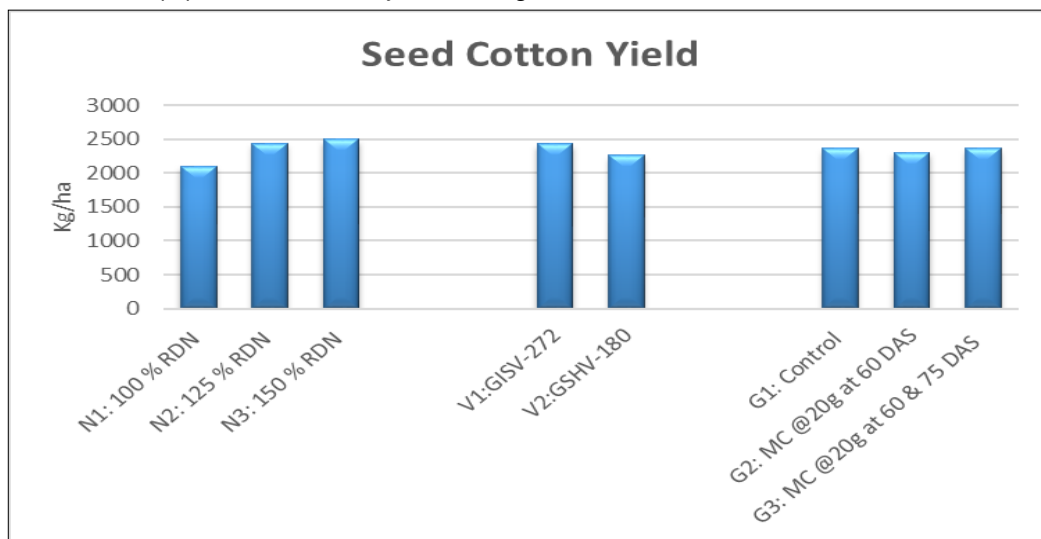
N was considerably lower compared to 150 kg N (42).

The present investigation on high density planting and canopy management through nutrition and growth regulator showed seed cotton yield in the range of 22 to 24 Q/ha which was almost 1.5 to 2.0 times higher than the normal sowing in the rain fed regions. Thus, the HDPS of cotton, their demonstrations and suitable policy reforms and mechanization hold great promise in increasing the productivity of the cotton in India. Further, the predictive modelling and forecasting through 3D immersive virtual reality and digital metaverse technology as well as use of generative AI in cotton production system (43, 44) showcasing need to change policy reforms that aided to implement HDPS cotton growing network with suited genotypes, proper nutrient management and growth based canopy architecture, the traceability of raw materials supplied to the network of automated ginning and network of automated processing across different states of India paved the way for better trading across the globe. The same modelling may also be used for cotton seed production systems as well as the subsidiary industries like cotton seed oil mills, animal feed producing industries and waste reprocessing in the textile industries that paved way collaborative economic value co-creation across industries (45). Further, the technology transfers specifically of suitable genotypes under HDPS and canopy management can be exploited through corporate giants under corporate social responsibility (CSR) for faster dissemination not only to the internal ends of the cotton growing rural regions of the country, but also to the UN member countries of the Africa and Sub Saharan regions for enhancing the socioeconomic condition of the farmers through better productivity and profits (46). The portfolio managers may attract huge

Table 5. Economics of different treatments

Treatment	Seed cotton yield (kg/ha)	Cost of cultivation (Rs./ha)	Gross income (Rs./ha)	Net income (Rs./ha)	BCR
N- Nitrogen Levels					
N1: 100 % RDN	2103	62916	147224	84307	2.34
N2: 125 % RDN	2441	66993	170838	103845	2.55
N3: 150 % RDN	2505	68364	175339	106975	2.56
V-compact genotype					
V1: GISV-272	2433	66928	170334	103406	2.54
V2: GSHV-180	2266	65254	158600	93346	2.43
G-growth Regulator					
G1: Control	2370	64247	165924	101677	2.58
G2: MC at 20 g at 60 DAS	2309	65685	161627	95941	2.45
G3: MC at 20 g at 60 & 75 DAS	2369	68341	165850	97509	2.42

RDN-Recommended dose, MC-Mepiquat chloride, DAS-Days after sowing.

**Fig. 1.** Effect of nitrogen and growth regulators on seed cotton yield (pooled).

RDN- Recommended dose of nitrogen, DAS- Days after sowing, MC- mepiquate chloride.

investment from corporate giants to invest in automated HDPS production, multi-product processing (seed, oil, animal feed etc.) and trading system in unexploited areas of African and Sub-Saharan region to uplift the socio-economic conditions of the poor nations (47). The current trends and policy changes in agriculture promote the contract or corporate farming in large areas where laborers are scarce and automation is required that attract and encourage private investment in multiple value chain business (48).

Conclusion

Based on our findings in the present work, we conclude that the optimum nitrogen level flurries plant growth and increase seed cotton yield per unit area under HDPS of cotton and hence nitrogen should be applied till favorable BCR. In this experiment, the black cotton soil under rain fed area of the Agro-climatic zone II of high rainfall region (> 800 mm rain), 125 % RDN (281 kg) is suitable nitrogen level under HDPS sowing for higher seed cotton yield for getting maximum BCR. Mepiquat chloride application reduces plant height, sympodial length, LAI and shoot to root ratio without influencing number of sympodia, number of boll and seed cotton yield aiding altering plant architecture amenable to mechanical picking and indirectly influencing reduction of costs for cotton cultivation. We also opined that the timing and environment is very critical to use MC, especially under HDPS of cotton to manage crop

canopy architecture. In our study, genotype, GISV 272 and 125 % of recommended nitrogen level under HDPS in rain fed region of Gujarat showed better performance and economics.

In-depth studies on effect of MC on canopy management under different environments, proper application time and doses at critical growth stages need to standardize. The nano formulations of nutrients and growth regulators for sustained release and longer residual effect to be studied for HDPS cotton and mechanization.

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Authors' contributions

VKV was responsible for conceptualizing the research, collecting relevant literature, overall supervision, data recording and preparation of the original manuscript draft. HRR developed the research layout and provided overall supervision throughout the study. RDP carried out statistical analysis and interpretation. PRP, RBK and RKK contributed to writing and editing and provided valuable suggestions. GOF, MMP and HRD offered guidance in

conducting the experiment and provided suggestions, comments and corrections to the manuscript. All authors 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

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