

Original Research Article

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Influences of Different Planting Density on Growth, Yield Attributes and Yields of *hirsutum*, *arboreum* and Bt Cotton

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ABSTRACT

An optimum plant population can maximize the plant output so this field experiment was conducted to know about the Response of different planting density on various genotypes of cotton for yield maximization. In this experiment three cotton genotypes viz. *hirsutum* cotton (AKH-081), *arboreum* cotton (AKA-7) and Bt cotton (Balwan), with three plant densities level of 100 %, 150 % and 200 % of normal for respective genotype, were laid out in factorial randomized block design. Bt cotton Balwan recorded higher growth in terms of leaf area, dry matter weight and yield attributes plant⁻¹. Plant height and sympodial branches plant⁻¹ were significantly more with AKA 7. AKA-7 recorded maximum seed cotton yield (1715 kg ha⁻¹) than Bt Balwan (1571 kg ha⁻¹) and AKH 081(1466 kg ha⁻¹). High density planting at 200% of normal density produced maximum seed cotton yield (1802 kg ha⁻¹) at par with 150% of normal plant density (1679 kg ha⁻¹). Normal planting density recorded the maximum harvest index (38.08%) and seed index (7.54) followed by high population densities of 150% and 200%. whereas balwan observed high seed index followed by AKH-081 and AKA-07. Highest ginning out turn recorded by AKA-07 followed by AKH-081 and Balwan but 200% planting density reported maximum ginning out turn than 150% and 100% planting density. Increased plant population compensated for fewer yield attributes plant⁻¹ and cumulatively yield output was higher in conventionally close spaced genotype (AKA-7) and with the high density planting system.

Keywords

Planting Density, Growth, Yield Attributes, Yields of *hirsutum*, *arboreum* and Bt Cotton

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Introduction

Cotton is in predominant position among all cash crops in India and has retained its unique fame as 'king of fibre' and 'white gold' because of its higher economical value among all cash crops. In India, nearly 70 per cent of the crop is cultivated under rainfed conditions in the Central and Southern regions of the country and it is essential to investigate the suitable genotype which performs better under

this condition. There is much scope to increase the cotton production in India by increasing the productivity through adoption of appropriate agronomic practices. The current economic climate continues to impact profit margins. With production cost on the rise due in part to increased seed cost associated with transgenic technologies, producers are searching for ways to increase efficiency. This has led to changes in seeding rates, row spacing and row-configurations such as solid

planted, twin-rows, and skip-row patterns. With the advent of precision seed drop planters and GPS control systems, producers can manipulate plant populations to optimize yield. There is also a need to find out optimum plant density for recently released cotton hybrids to realize the maximum yield potential. Hence, the need to find out the potentiality of cotton genotypes and also to save cotton seeds with different plant densities under rainfed condition. So this study was conducted with the objective to screen out the rational plant density for yield maximization in *arboreum*, *hirsutum* and *Bt* cotton under the high density planting system.

Materials and Methods

Experimental site

A field investigation was carried out with the objective of the “Influence of different plant density on growth, yield attributes and yield of *arboreum*, *hirsutum* and *Bt* cotton” at the All India Coordinated Research Project on Agrometeorology, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India during the kharif season of 2015-16. Akola is situated in the sub-tropical zone at the latitude of 22^o42' North longitude of 77^o 02' East. The altitude of the place is 307.41 meter above mean sea level.

Soil and climate

The soil of experimental plot was medium deep black with fairly uniform and levelled topography with slightly alkaline in reaction with medium status of organic carbon content, available nitrogen and phosphorus and fairly rich status of available potassium. The climate of Akola is semi-arid and characterized by three distinct seasons *viz.*, hot and dry summer from March to May, warm and rainy monsoon from June to October and mild cold winter from November to February. Most of the rain

received from south-west monsoon during June to October with mean annual normal precipitation of 788.9 mm received in 43.7 rainy days (Average of 30 years, 1981-2010). Total rainfall of 590.8 mm was recorded during the crop growing season. The crop encountered two dry spell periods during first fortnight of July (23 days) and second fortnight of August (15 days). Genotype AKH 081 was found susceptible to bollworm incidence. Sap sucking pest infestations (aphids, jassids and whiteflies) and bollworm attacks were controlled by undertaking timely plant protection measures.

Treatment details

Three cotton genotypes *viz.* *hirsutum* cotton, *arboreum* cotton and *Bt* cotton, with three plant densities at the population level of 100 %, 150 % and 200 % of normal for respective genotype, were laid out in factorial randomized block design with three replications. The cotton crop was sown on June 18, 2015 and harvested in four pickings up to last week of December, 2015.

The important research findings are briefed below:-

Result and Discussion

Growth studies

Plant Height (cm)

Plant height increased as the crop advanced in age. The rate of increase in plant height was the maximum between branching to flowering stage. Subsequently the rate of increase was gradual down towards maturity stage.

Effect of Genotype

Plant height was significantly influenced throughout the crop growth period by different

genotypes. At 30 day after emergence (DAE), Bt cotton Balwan recorded significantly higher plant height than AKH-081 and AKA-7 which were at par. Subsequently at 60, 90, 120, 150 DAE and at harvest stage, *arboreum* genotype AKA-7 attained significantly higher plant height over the remaining two genotypes. AKH-081 recorded the least plant height. Balwan recorded significantly higher plant height than AKH-081. Anwar *et al.*, (2002), Copur (2006) and Moola and Giri (2006) noticed that the differences observed for plant height among cotton genotypes can be primarily attributed to variation in genetic makeup of plants. Moreover, different genotypes respond in different degrees to the abiotic and biotic factors.

Effect of Plant density

Differences due to plant density on plant height were found to be non-significant at 30, 60 and 90 DAE. Subsequently, from 90 DAE to harvest stage, maximum plant height was recorded in normal planting density with 100% population (P_1), which was significantly superior over high density planting at 200% of normal population (P_3) and at par with high density planting with 150% population (P_2). Treatments P_2 and P_3 varied non-significantly between them. These results are in conformity with Kater Hake *et al.*, (1991) according to whom cotton seedlings tend to grow taller in thick stands. As the season progresses, plant height in thick stands tend to lag behind that of thin stands and at harvest, high density stands have the lowest average plant height. In cotton grown in ultra-narrow rows (UNR) although canopy closure was earlier, this early canopy closure did not translate into faster growth or development as high populations lead to excessive competition for photo-assimilates (Rose Roche *et al.*, 2003). Also Plant spacings directly influence soil moisture extraction, light interception, humidity and wind movement. These factors, in term,

influence plant height. Singh *et al.*, (2015) also reported that plant height attained its apogee at wider spacing. Dongsheng Zhang *et al.*, (2014) also observed decreased cotton plant height with increased plant density above the optimum planting density.

Number of sympodial branches /plant

Data on number of sympodial (fruiting) branches plant^{-1} were recorded from 60 DAE to 120 DAE. Sympodial branches plant^{-1} increased with increase in age of crop and attained maximum value at 120 DAE when boll bursting rate was at peak.

Effect of Genotype

The effect of genotype on sympodial branches plant^{-1} was recorded significant among different genotype at 60 DAE, 90 DAE and 120 DAE. Different genotypes had significant influence on number of sympodial branches plant^{-1} . Genotype AKA 7 (V_2) recorded maximum number of sympodial branches plant^{-1} from 60 days up to 120 DAE and it was significantly superior over Balwan (V_3) and AKH 081 (V_1). Balwan produced significantly more number of sympodial branches plant^{-1} as compared to AKH 081. The significant differences in number of sympodial branches plant^{-1} among varieties of different genotypes was also have been reported by Copur (2006), Giri *et al.*, (2008) and Bharathi *et al.*, (2012). The differences in number of sympodial branches plant^{-1} can be attributed to differences in genetic makeup of the genotypes, wherein in due to more plant height, duration and deep rooted system, number of sympodial branches also increases relative to the different genotypes.

Effect of Plant density

The number of sympodial branches plant^{-1} was found to vary non significantly among

different plant densities at 60 DAE and 90 DAE. But numerically normal planting at a level of 100% was recorded more number of sympodial branches plant⁻¹ than high density planting at a level of 150 % and 200 % at 60 DAE and 90 DAE. At 120 DAE, normal plant density (100%) recorded maximum number of sympodial branches plant⁻¹ (17.33) at par with high density planting at 150 % (P₂) and significantly higher than high density planting at 200% (P₃). Treatments P₂ and P₃ were statistically at par. This shows greater encouragement for reproductive growth in individual plant under normal planting density. Plant spacings directly influence resources use which in turn influences branching. Under high density planting there may be excess competition for photo-assimilates needed for reproductive development. Plants direct lower percentage of daily produced total dry mass to reproductive development (Darawsheh *et al.*, 2007). Whereas, Wali and Koraddi (1989), Jagtap and Bhale (2011), Paslawar *et al.*, (2015) and Shekar *et al.*, (2015) reported that increasing planting density affected the plant dry matter partitioning that related with number of sympodial branches plant⁻¹. With increases in planting density, Number of sympodial branches plant⁻¹ were decreases.

Leaf area per plant

Effect of Genotype

Different genotypes had significant influence on the leaf area plant⁻¹ observed at 60, 90 and 120 days after emergence of crop. At all the observed stages of observation Bt cotton genotype Balwan (V₃) produced significantly higher leaf area plant⁻¹ than *hirsutum* genotype AKH 081 (V₁) and *arboreum* genotype AKA 7 (V₂). The latter two genotypes produced statistically similar leaf area plant⁻¹ at all the stages. Bt balwan and *hirsutum* AKH 081 genotypes have Broad-leaf expression while

arboreum AKA 7 has okra leaf shape. However, AKA 7 genotype bears more number of leaves compensating for its comparatively lower area of individual okra leaf. Differences in leaf area plant⁻¹ may be mainly ascribed to differences in genetic makeup of the genotypes.

Effect of Plant density

Differences in leaf area plant⁻¹ due to different planting densities were significant and leaf area plant⁻¹ showed decreasing trend with increasing plant density (P₁ to P₃) at all the observed growth stages of the crop. Normal planting density (100%) produced significantly higher leaf area plant⁻¹ at all observed stages of crop growth. However, it was on par with high density planting at 150% of normal population (P₂), except at 120 DAE, and statistically more over high density planting at 200% (P₃). Treatment P₂ was statistically equivalent to P₃ except at 120 DAE whereat it noted significantly higher leaf area plant⁻¹ than P₃. Maximum leaf area plant⁻¹ with lower plant density could be due to higher number of leaves plant⁻¹ and better leaf expansion as a consequence of more favourable share of resources (moisture, light radiation and nutrients) by individual plant.

Leaf area index

Leaf area index characterizes the canopy-atmosphere interface, where most of the energy fluxes exchange. Leaf area index (LAI) was computed treatment wise from 30 to 120 DAE.

Effect of Genotype

Leaf area index was the maximum with AKH 081(V₁) at 30 and 60 DAE. At 90 and 120 DAE it was maximum with AKA 7(V₂). However, both genotypes were statistically at par with each other and exhibited significantly

higher LAI as compared to Bt cotton Balwan (V₃). This could be mainly due to relatively wider plant spacing of Bt cotton genotype accommodating more ground area plant⁻¹, although it produced significantly higher leaf area plant⁻¹.

Effect of Plant density

Plant density significantly influenced the leaf area index. Leaf area index showed increasing trend with increasing plant density (P₁ to P₃) at all the observed growth stages. High density planting at 200% of normal population (P₃) showed significantly higher leaf area index than 150% (P₂) and normal (100%) planting densities. Reduced ground area plant⁻¹ with higher population densities caused more LAI in high density planting. This corroborates the findings of Dongsheng Zhang *et al.*, (2014) who observed that cotton leaf area index increased but plant height decreased with plant density. Treatment combinations of genotypes AKH-081 and AKA 7 with high density planting at 200 % of normal population (V₁P₃ and V₂P₃), being at par with each other, recorded significantly higher LAI than the rest at 30, 60,90 and 120 DAE. Both AKH-081 and AKA-7 genotypes recorded statistically similar LAI at the corresponding level of plant density. Genotype Balwan under all the three plant density levels recorded significantly lower LAI compared to the remaining two genotypes at all the stages of observed interaction effect. According to Babiker *et al.*, (2006) leaf area index (LAI) which can be used as a measurement of light interception efficiency increased via increasing plant density with concomitant yield decrease due to shading. On the other hand, the decrease in specific leaf weight (SLW) with the increase in plant density indicated that leaves of the highest density had less weight per leaf area and therefore were very thin and they behaved like shade leaves because of competition for light.

Leaf area index interaction

Treatment combinations of genotypes AKH-081 and AKA 7 with high density planting at 200 % of normal population (V₁P₃ and V₂P₃), being at par with each other, recorded significantly higher LAI than the rest at 30, 60,90 and 120 DAE. Both AKH-081 and AKA-7 genotypes recorded statistically similar LAI at the corresponding level of plant density. Genotype Balwan under all the three plant density levels recorded significantly lower LAI compared to the remaining two genotypes at all the stages of observed interaction effect. According to Babiker *et al.*, (2006) leaf area index (LAI) which can be used as a measurement of light interception efficiency increased via increasing plant density with concomitant yield decrease due to shading. On the other hand, the decrease in specific leaf weight (SLW) with the increase in plant density indicated that leaves of the highest density had less weight per leaf area and therefore were very thin and they behaved like shade leaves because of competition for light.

Dry matter weight per plant

Total dry matter production is the integral component of crop growth rate over the entire growth period, and it is related to grain yield by the harvest index. During the crop growing period increase in dry matter weight plant⁻¹ (g) was continuous up to 150 DAE, from 2.28 to 68.23 g. Subsequently at harvest it declined (52.16 g) due to leaf senescence and picking of burst bolls. The rate of increase was very slow up to 30 days (3.34%). Thereafter it accelerated with stage of growth i.e. at 60 (26.71%), 90 (64.86%) till 120 days (90.22%). From 120th day further increase till 150 DAE was comparatively small (9.78%). Therefore the maximum quantitative increase in dry matter weight was observed between 60 to 90 DAE followed by 90 to 120 DAE.

Effect of Genotype

Different genotypes showed significant differences in dry matter weight plant⁻¹(g) at various growth stages. Bt cotton Balwan (V₃) accumulated significantly higher dry matter weight plant⁻¹ as compared to AKH 081 (V₁) and AKA 7 (V₂) at all stages of crop growth. Genotype AKA 7 recorded significantly higher dry matter weight plant⁻¹ than AKH-081 (V₁) at 60, 90, 120 and 150 DAE, however, being statistically at par at 30 DAE and harvest stage. Bt cotton Balwan inherently produced comparatively more vegetative/reproductive growth in terms larger leaves, resultantly larger leaf area plant⁻¹ and hence more photo-assimilates to cater greater number bolls plant⁻¹ and higher boll weight consequently causing higher dry matter weight plant⁻¹ (Sisodia and Khamparia, 2007; Giri *et al.*, 2008; and Ban, 2015).

Effect of plant density

Total dry matter accumulation (g) plant⁻¹ was significantly influenced due to different plant densities at various growth stages of cotton. Cotton plants under normal planting density (P₁) accumulated significantly higher dry matter plant⁻¹ than both high planting densities of 150% (P₂) and 200% (P₃) of normal population at all observed crop growth stages. However, It was at par with 150% planting density at 30 and 60 DAE. Similarly 150% and 200% planting densities were at par at 30 and 60 DAE but subsequently from 90 DAE till harvest stage the former proved significantly. Darawsheh *et al.*, (2007) and Jadhav *et al.*, (2015) noticed that Plant spacing directly influences soil moisture extraction, light interception, soil nutrients use, canopy aeration etc. which in turn influence vegetative and reproductive development of a plant. Under high density planting as root and leaf surfaces become larger plants compete for growth resources and with excessive

competition for limited resources each plant in a dense stand receives less sunlight, water and nutrients which translate into reduced photo-assimilates and hence lower dry matter production plant⁻¹.

Yield attributing characters

Number of picked bolls per plant

Effect of Genotype

Genotypic differences in influencing the number of picked bolls plant⁻¹ were found to be significant. Bt cotton Balwan (V₃) recorded significantly higher number of picked bolls plant⁻¹ (17.59) as compared to *arboreum* genotype AKH 081 (V₂, 6.78) and *hirsutum* genotype (V₁, 5.58). Number of picked bolls plant⁻¹ in AKA 7 was significantly more than AKH 081, which recorded the least number of picked bolls plant⁻¹. Copur (2006), Singh *et al.*, (2012) and Ban (2015) noticed that the differences among genotypes for number of picked bolls plant⁻¹ might have been due to the difference in genetic potential of the genotypes and comparatively higher retention of bolls by Bt cotton genotype.

Effect of Plant density

Number of bolls picked plant⁻¹ was the maximum with normal planting density of 100% population (P₁, 11.67) which was significantly more over high planting densities of 150% (P₂, 9.77) and 200% (P₃, 8.51) of normal population. Treatment P₂ (HDP-150%) produced significantly higher number of bolls plant⁻¹ than P₃ (HDP-200%). Higher plant population under high density planting causes competition and fewer shares of limited resources to individual plants. Moreover, lower the plant population per hectare may increase light penetration to allow more resources for fruit development lower in the canopy which may increase retention and

hence number of bolls. Kater Hake (1991) found that in dense stands fruiting branches are 25% shorter with more fruiting up the plants and slow development of new nodes. Resultantly plants produced fewer fruiting bodies and mature fruits plant⁻¹. Whereas, Singh and Rathore (2007), Jahedi *et al.*, (2013) and Paslawar *et al.*, (2015) found that under normal planting density overall favourable plant growth and development reflected in better source - sink relationship, which in turn enhanced the yield attributes.

Boll weight (g)

Effect of Genotype

An evaluation of data indicated that greatest boll weight was recorded in Bt cotton Balwan (3.21 g) and it was significantly higher over that of *hirsutum* cotton AKH 081 (2.10 g) and *arboreum* cotton AKA 7 (2.01). The latter two genotypes were statistically at par with each other. Among Bt and non-Bt cultivars have Significant differences in their average boll weight (Hofs *et al.*, 2006 and Ban, 2015).

Effect of Plant density

The boll weight was significantly influenced due to different plant densities. Normal planting at 100% population (P₁) recorded the maximum boll weight which was at par with 150% of planting density (P₂) and significantly higher over 200% planting density (P₃). According to Rose Roche (2003) under ultra-narrow system in cotton less light is available to leaves lower in the canopy that are important for supporting boll growth.

This may be one reason why boll size is smaller despite there being fewer bolls plant⁻¹. Venugopalan *et al.*, (2011^a) reported that in both *G. hirsutum* and *G. arboreum* genotypes the boll weight and harvest index decreased with increasing plant density. Paslawar *et al.*,

(2015) also observed that that boll weight increased with decreased plant densities.

Seed cotton weight (g) per plant

Effect of Genotype

Differences in seed cotton weight plant⁻¹ of genotypes AKH 081 (V₁), AKA 7 (V₂) and Balwan (V₃) were observed to be significant. Genotype Balwan recorded significantly higher seed cotton weight plant⁻¹ (56.49 g) as compared to AKA 7 (14.34 g) and AKH 081 (11.44 g). Also weight of seed cotton plant⁻¹ noted in AKA 7 was significantly more than AKH 081. The maximum seed cotton weight plant⁻¹ with Bt cotton Balwan can be attributed to better expression of yield components *viz.* maximum number of number of bolls and boll weight than other two genotypes. These results are supported by Hofs *et al.*, (2006) and Ban (2015). They were observed that cotton plant have genetically difference in boll retention, boll weight and number of bolls plant⁻¹ that affect the seed cotton yield plant⁻¹.

Effect of Plant density

Among different plant densities, seed cotton weight plant⁻¹ was highest with normal planting density of 100% population (P₁, 33.97 g) which was significantly higher over high planting densities of 150% (P₂, 27.44 g) and 200% (P₃, 20.87 g) of normal population. Treatment P₂ (HDP-150%) produced significantly higher seed cotton weight plant⁻¹ than P₃ (HDP-200%). Giri *et al.*, (2008) and Darawsheh *et al.*, (2009) observed that normal or optimum plant population while optimizing resource use produced more boll number and boll weight that reflected in higher seed cotton weight plant⁻¹. Under high density population probably due to reduced availability of resources to individual plant resultantly fewer boll number and smaller boll weight reflected in reduced seed cotton weight plant⁻¹.

Table.1 Treatment details along with symbol used

Treatment	
A	Genotype
V ₁	AKH-081 (<i>hirsutum</i>)
V ₂	AKA-7 (<i>arboreum</i>)
V ₃	Balwan (<i>Bt Cotton</i>)
B	Plant density
P ₁	NP - 100% (60x15 cm*, 90x45cm**) (111111, 24691 plants ha ⁻¹)
P ₂	HDP -150% (60x10 cm*, 90X30 cm**) (166666, 37037 plants ha ⁻¹)
P ₃	HDP - 200% (45x10 cm*, 45x45cm**) (222222,49382 plants ha ⁻¹)

* spacing of arboreum and hirsutum genotypes, ** spacing of Bt genotype
V-Variety, P-Planting density, NP-Normal planting density, HDP-High density planting

Table.2 Growth parameters as influenced by various treatments

Treatment	Plant height (cm)	Number of sympodial branches plant ⁻¹	Leaf area plant ⁻¹ (dm ²)	Leaf area index	Total dry matter accumulation plant ⁻¹ (g)
Genotype					
V ₁ -AKH 081	80.6	12.20	20.05	3.439	24.51
V ₂ -AKA 7	121.6	19.27	21.20	3.628	28.76
V ₃ -Balwan	102.7	16.60	33.02	1.197	103.21
SE(m)±	3.3	0.61	0.51	0.069	1.73
CD (p=0.05)	9.9	1.84	1.53	0.207	5.20
Plant density					
P ₁ -NP 100%	107.3	17.33	27.02	2.048	58.13
P ₂ -HDP 150%	102.0	15.84	24.87	2.787	51.86
P ₃ -HDP 200%	95.6	14.89	22.39	3.430	46.49
SE(m)±	3.3	0.61	0.51	0.069	1.73
CD (p=0.05)	9.9	1.84	1.53	0.207	5.20
Interaction					
SE(m)±	5.7	1.06	0.89	0.119	3.00
CD (p=0.05)	NS	NS	NS	0.358	NS
GM	101.6	16.02	24.76	2.755	52.16

Table.3 Leaf area index as influenced by treatment interaction

Genotype/ Plant density	P ₁ -NP 100%	P ₂ -HDP 150%	P ₃ -HDP 200%
V ₁ -AKH 081	2.556	3.479	4.283
V ₂ -AKA 7	2.708	3.623	4.553
V ₃ -Balwan	0.881	1.259	1.453
SE(m) _±	0.119		
CD (p=0.05)	0.358		

Table.4 Yield related parameters as influenced by various treatments

Treatment	Number of picked bolls plant ⁻¹	Boll weight (g)	Seed cotton weight (g plant ⁻¹)	Seed cotton yield (kg ha ⁻¹)	Cotton stalk yield (kg ha ⁻¹)	Biological yield (kg ha ⁻¹)	Harvest index (%)	Ginning out turn (%)	Seed Index (g)
Genotype									
V ₁ -AKH 081	5.58	2.10	11.44	1466	2718	4184	35.12	38.92	7.64
V ₂ -AKA 7	6.78	2.01	14.34	1715	3038	4753	36.31	40.11	6.10
V ₃ -Balwan	17.59	3.21	56.49	1571	2443	4014	39.50	37.87	8.65
SE(m) _±	0.38	0.09	0.77	46	90	130	0.48	0.14	0.04
CD (p=0.05)	1.14	0.27	2.32	138	271	391	1.44	0.41	0.11
Plant density									
P ₁ -NP 100%	11.67	2.65	33.97	1271	2080	3351	38.08	38.81	7.54
P ₂ -HDP 150%	9.77	2.56	27.44	1679	2781	4460	37.77	39.00	7.50
P ₃ -HDP 200%	8.51	2.11	20.87	1802	3338	5140	35.07	39.09	7.35
SE(m) _±	0.38	0.09	0.77	46	90	130	0.48	0.14	0.04
CD (p=0.05)	1.14	0.27	2.32	138	271	391	1.44	NS	0.11
Interaction									
SE(m) _±	0.66	0.16	1.34	79	156	226	0.83	0.24	0.06
CD (p=0.05)	NS	NS	4.01	NS	NS	NS	NS	NS	NS
GM	9.98	2.44	27.42	1584	2733	4317	36.97	38.96	7.46

Table.5 Seed cotton weight plant⁻¹ (g) as influenced by treatment interactions

Genotype/ Plant density	P₁-NP 100%	P₂-HDP 150%	P₃-HDP 200%
V₁-AKH 081	15.07	11.55	7.70
V₂-AKA 7	18.47	14.27	10.30
V₃-Balwan	68.37	56.50	44.60
SE(m)±	1.34		
CD (p=0.05)	4.01		

Table.6 Seed cotton yield (kg ha⁻¹) under different treatment interactions

Genotype/ Plant density	P₁-NP 100%	P₂-HDP 150%	P₃-HDP 200%
V₁-AKH 081	1135	1569	1694
V₂-AKA 7	1445	1813	1886
V₃-Balwan	1231	1655	1826
SE(m)±	79		
CD (p=0.05)	NS		

Interaction effect

Treatment combination of Bt cotton genotype Balwan with normal density planting (V_3P_1), recorded significantly higher seed cotton weight plant^{-1} than rest of the combinations. Both AKH-081 and AKA-7 genotypes recorded statistically similar seed cotton weight plant^{-1} at the corresponding level of plant density. AKA-7 and AKH-081 under all the three plant density levels recorded significantly lower seed cotton weight plant^{-1} compared to Balwan at the corresponding level of plant density.

Yield studies

Seed cotton yield (kg/ha)

Effect of Genotype

All the cotton genotypes differed from each other for seed cotton yield ha^{-1} . AKA 7 (*G. arboreum*) registered significantly higher seed cotton yield (1715 kg ha^{-1}) than Bt cotton Balwan (1571 kg ha^{-1}) and *hirsutum* non-Bt AKH 081 (1466 kg ha^{-1}). The latter two genotypes were statistically at par. Among the three genotypes Bt cotton Balwan produced maximum leaf area plant^{-1} , dry matter weight plant^{-1} , greater number and size (weight) of bolls and higher seed cotton weight plant^{-1} followed by genotypes AKA 7 and AKH 081.

Genotype AKA 7 although had lower leaf area plant^{-1} , dry matter weight plant^{-1} , smaller boll size and fewer bolls plant^{-1} and seed cotton weight plant^{-1} , however, its conventional density accommodating markedly higher per unit population than in Balwan, compensated for lower values of yield attributes plant^{-1} and produced higher yield level with better tolerance to the short term weather fluctuations during the growing season (Jagvir Singh *et al.*, 2012). Comparatively lower yield level in AKH 081 appears to be more due to incidence of

bollworm complex, besides its genetic potential (Venugopalan *et al.*, 2011).

Effect of Plant density

High density planting at 200% of normal density (P_3) produced maximum seed cotton yield (1802 kg ha^{-1}) which was at par with seed cotton yield obtained (1679 kg ha^{-1}) under 150% of normal plant density (P_2). Normal plant density (100%) yielded the least seed cotton (1271 kg ha^{-1}). The high density planting treatments (HDP-200% and HDP-150%) generally had smaller individual boll size (weight) and fewer bolls plant^{-1} , however, the increased number of plants compensated for fewer boll number and smaller boll size and cumulatively yield output was significantly higher in both the high density planting treatments as compared to conventional (100%) planting density. These results are in agreement with reports of Bhalerao *et al.*, (2012) and Paslawar *et al.*, (2015).

Interaction effect

Interaction effects between treatments were found to be statistically non-significant. However, the seed cotton yield data under treatment interactions are given in Table for numerical comparison. Numerically treatment combination of V_2P_3 (AKA 7 at HDP-200%) yielded maximum seed cotton (1886 kg ha^{-1}) closely followed by V_3P_3 (Balwan at HDP-200%) yielding 1826 kg ha^{-1} seed cotton and V_2P_2 (AKA 7 at HDP-150%) yielding 1813 kg ha^{-1} seed cotton. Numerically the least seed cotton yield occurred under the treatment combination of V_1P_1 (1135 kg ha^{-1}).

Cotton stalk yield (kg/ha)

Effect of Genotype

Differences in stalk yield were significant among the genotypes under study. Genotype

AKA 7 (V₂) recorded significantly higher stalk yield (3038 kg ha⁻¹) and comparatively significant decline in stalk yield was noticed under genotypes Balwan (V₃-2443 kg ha⁻¹) and AKH 081 (V₁-2718 kg ha⁻¹).

Effect of Plant density

Differences in stalk yield due to different planting densities were significant. HDP-200% (P₃) recorded significantly higher stalk yield (3338 kg ha⁻¹); followed by HDP-150% P₂ (2781 kg ha⁻¹) and NP-100% P₁ (2080 kg ha⁻¹).

Biological yield (kg/ha)

Effect of Genotype

Among the different genotypes, biological yield (kg ha⁻¹) differed significantly. Maximum biological yield (4753 kg ha⁻¹) was recorded with genotype AKA-7 (V₂) which was significantly superior to AKH-081 V₁ (4184 kg ha⁻¹) and Balwan V₃ (4014 kg ha⁻¹).

Effect of Plant density

Biological yield differed significantly due to various plant densities. Significantly higher biological yield (5140 kg ha⁻¹) was obtained with high density planting at 200% of normal population (P₃).

Next best treatment was high density planting at 150% of normal population P₂ (4460 kg ha⁻¹). Conventional planting at 100% population (P₁) produced the lowest biological yield (3351 kg ha⁻¹).

Although high planting densities (HDP-150% and HDP-200%) had lower dry matter accumulation by plants individually, however, with higher population cumulatively total biomass output was higher than under conventional planting density (NP-100%).

Harvest index

High harvest index is an indicative of better translocation and mobilization of food reserve (Morthy and Rao, 1986, Rauf and Sadaqat, 2008).

Effect of Genotype

Cotton genotypes exhibited significant differences in terms of harvest index. Bt cotton genotype Balwan V₃ recorded significantly higher harvest index (39.50%) whereas hirsutum non-Bt AKH 081 V₁ recorded the lowest harvest index (35.12%). As such both non-Bt genotypes i.e. *arboreum* AKA 7 (36.31%) and *hirsutum* AKH 081 were statistically at par. Higher harvest index shows better translocation efficiency in genotype Balwan.

Effect of Plant density

Differences in harvest index due to different planting densities were statistically significant. NP-100% (P₁) recorded the maximum harvest index (38.08%) significantly higher than HDP-150% P₂ (37.77%), HDP-200% P₃ (35.07%).

The finding shows better translocation efficiency under conventional planting (100%) as compared to high planting densities (HDP-150% and 200%).

Venugopalan *et al.*, (2013) also reported that harvest index decreases due to increase of leaf area index associated with high population densities reduce the efficiency of photosynthetic photon flux density interception per plant area.

In this case a greater proportion of photo-assimilates is directed to the vegetative growth rather than reproductive thus reducing harvest index (Darawsheh *et al.*, 2007).

Ginning out turn (%)

Effect of Genotype

Data revealed that ginning out turn was significantly influenced by genotypic differences. The highest value of ginning out turn (40.11%) was obtained in case of genotype AKA 7. It was followed by AKH 081 (38.92%) and Balwan (37.87%). These findings are in consonance with those reported by by Copur (2006) and Ban (2015).

Effect of Plant density

Ginning out turn did not differ significantly under different plant densities. Numerically, high density planting at 200% recorded maximum ginning out turn (39.09%) followed by high density planting at 150% (39.00%) and normal planting density at 100% (38.81). Reddy and Gopinath (2008), Reddy and Kumar (2010) also reported that ginning percentage was free of population pressure.

Seed index

Effect of Genotype

Genotypic differences were significant for seed index. Bt cotton genotype Balwan (V_3) recorded higher seed index (8.65 g) followed by *hirsutum* AKH 081 (V_1 -7.64 g) and *arboreum* AKA 7 (V_2 -6.10 g) genotypes.

Effect of Plant density

Seed index was significantly influenced by different planting densities. Normal planting density at 100% population level (P_1) noted higher seed index (7.54 g). It was statistically at par with high density planting at 150% population level (P_2 -7.51 g) And significantly more than 200% population level (P_3 -7.35 g) Treatment P_2 also proved superior to P_3 . This appears in contrast to Darawsheh *et al.*,

(2007) who observed that plants in narrow row high population density produced lower fibre proportion or higher seed proportion. However, according to Dhillon *et al.*, (2006) plants under wider plant spacing produced higher seed index.

On the basis of the results obtained from present investigation following conclusions emerged.

Bt cotton genotype Balwan recorded higher growth in terms of leaf area, dry matter weight and yield attributes of individual plant than *arboreum* AKA-7 and *hirsutum* AKH 081 genotypes. Cotton planting at 150% to 200% of normal population density lowered growth and yield attributes of individual plant and caused earlier maturity of crop comparative to normal population density. Whereas, Cotton genotype AKA-7 (*G.arboreum*) recorded the maximum seed cotton yield per hectare followed by Balwan (Bt cotton) and AKH-081(*G.hirsutum*). High density planting at 200% of normal population density produced maximum seed cotton yield per hectare which was at par with seed cotton yield from 150% of normal population density. The increased number of plants compensated for fewer yield attributes plant^{-1} and cumulatively yield output was higher in conventionally close spaced genotype (AKA-7) and with the high density planting system (150% to 200% of normal population density). Balwan recorded higher harvest index followed by AKA 7 and AKH 081. Ginning out turn was maximum in case of genotype AKA 7 but it found non-significant with planting densities while seed index was maximum with genotype Balwan and 100% planting density.

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