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RESEARCH PAPER

Performance of compact cotton genotypes under high density planting system at different fertilizer levels

MANJULA UDIKERI AND G.B. SHASHIDHARA

Department of Agronomy, College of Agriculture
University of Agricultural Sciences, Dharwad - 580 005, Karnataka, India
E-mail: manjulau3@gmail.com

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Abstract: Field experiments were conducted to study the performance of compact cotton genotypes under high density planting system and fertilizer levels during *kharif* 2014-15 and 2015-16 at University of Agricultural Sciences, Dharwad. The experiment was laid out in Strip-split plot Design with three replications. Genotypes, RAH-274, RAH-99 and DSC-1351 recorded significantly lower growth parameters (plant height, number of monopodial branches per plant and plant spread) and significantly higher dry matter production per plant, leaf area and leaf area index. Which were also produced significantly higher yield attributes (number of sympodial branches per plant, number of bolls per plant and boll weight), seed cotton yield (3,199, 3,156 and 3,134 kg ha^{-1}, respectively) and net returns (₹ 85,633, 83,845 and 82,899 ha^{-1}, respectively) than DHG-7-96. Closer spacing of 45 × 10 cm (2,22,222 plants ha^{-1}) recorded significantly higher seed cotton yield (3,372 kg ha^{-1}) and net returns (₹ 92,678 ha^{-1}) over other wider spacings. The application of higher dose of fertilizer (100:50:50 N, P_2O_5 and K_2O kg ha^{-1}) produced 5.42 per cent additional yield over lower dose of fertilizer. In interaction effect, genotypes RAH-274, RAH-99 and DSC-1351 each sown at spacing of 45 × 10 cm with the application higher dose of fertilizer of 100:50:50 N, P_2O_5 and K_2O kg ha^{-1} recorded significantly higher seed cotton yield (3,668, 3,575 and 3,497 kg ha^{-1}, respectively) and net returns (₹ 1,04,600, 1,00,701 and 97,411 ha^{-1}, respectively).

Key words: Compact cotton, Fertilizer levels, High density planting, Geometry

Introduction

Cotton (*Gossypium hirsutum* L.), is one of the most ancient and important commercial crop next to food grains. Due to its importance in agriculture as well as in industrial economy, it is also known as "white gold". India accounts cotton cultivation area of 12.70 million hectares, with a share of 21 per cent of the global production (30.50 million bales) with an average productivity of 523 kg lint ha^{-1} (Anon., 2015). In India, the seed cotton yield per unit area is still far below than many other cotton growing countries in the world. Among the various factors responsible for low yield of cotton crop in the country, low plant population and use of low potential varieties are of primary importance. Various techniques like maintaining suitable plant density, use of optimum dose of fertilizers, growth regulators *etc.,* are being used to overcome these constraints in cotton production. The optimum level of cotton would however depend on the plant type. The present day cotton genotypes have a long duration of 180-200 days; they are late maturing, tall growing and spreading types leading to bushy appearance. They also require the wide spacing resulting in the production of netted canopy there by posing problems in taking up plant protection measures, machine picking, inefficient in trapping of solar energy, physiological efficiency and harvest index. Because of longer duration, these varieties require more number of pickings, as a result leading to manifold increase in cost of cotton cultivation especially manual picking and the margin of profit is low and fluctuating in an erratic manner. Moreover, the availability of labour for clean picking is also a serious constraint. At present, in India, entire cotton is picked manually which is labour intensive and is becoming expensive day by day. On the contrary, about 30 per cent of world cotton production in Australia, Israel and USA is machine picked. Machine picking is a viable alternative to manual picking which will not only minimize cost of cultivation, but also reduce the dependency on labour. However, the pre-requisite for machine picking is the identification of cotton genotypes having short stature, earliness, compactness, sympodial growth habit and synchronous boll opening.

Under these circumstances, compact cotton genotypes are ideally suited. They offer great scope for reducing not only row width, but also spacing between the plants in a row. Ultra-narrow row (UNR) cotton production is considered as a potential strategy for reducing production costs by shortening the growing season. These compacts also provide the scope for increasing plant population per unit area by virtue of their shorter stature. It provides scope for double cropping and mechanical harvesting. These compact types have the added advantage of requiring few pickings only. Therefore, reduces the labour cost as well as seed cost as formers will use the varietal seeds during next sowing season. Proper major nutrient rates are also essential to maximizing lint production while minimizing input cost in UNR cotton. Ongoing cotton breeding research work at UAS, Dharwad has led to development of many compact varieties and they have high yielding potentiality in National/Zonal level of central and south India and some are under pre released agronomic investigation in central and south Indian cotton zone of rainfed situation. Thus realizing the need for assessing the performance of compact cotton varieties, this experiment was planned and carried out to study the performance of compact cotton genotypes under high density planting system at different fertilizer levels.

Material and methods

Field experiments were carried out during *kharif* 2014-15 and 2015-16 to know the performance of compact cotton genotypes under high density planting system at different fertilizer levels. The experiments were laid out at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad on medium black clay soil. The experiment consisted of 24 treatment combinations which were laid out in Strip split plot design with three replications. The treatment combinations included four genotypes (G_1-RAH-274, G_2-RAH-99, G_3-DHG-7-96 and G_4-DSC-1351) as horizontal strip plot treatments; three planting geometries *viz.*, S_1-60 × 15 cm (1,11,111 plants ha^{-1}), S_2-45 × 15 cm (1,48,148 plants ha^{-1}) and S_3-45 × 10 cm (2,22,222 plants ha^{-1}) as vertical strip plot treatments and two nutrient levels *viz.,* F_1-80:40:40 (100 % RDF) and F_2-100:50:50 (125 % RDF) kg N, P_2O_5 and K_2O ha^{-1} as intersectional plot treatments. FYM @ 5 t ha^{-1} was applied to all treatments uniformly. The cotton genotypes were sown on 22nd July 2014 for first year and 21st June 2015 for second year. In the first year, sowing was delayed due to delayed withdrawal of monsoon and while in the second year crop sown at right season with early onset of monsoon. The seeds were hand dibbled in the middle portion of furrow opened by maintaining space between row to row and plant to plant as per the plan in the experiment. To ensure even crop stand and to maintain required plant population, gap filling was done. Only one healthy and vigorous seedling per hill was retained after thinning. The plant protection measures were taken throughout the crop growth period as per the recommended schedule. The total rainfall received during 2014-15 was 1056.0 mm (71 rainy days) and the rainfall received during cropping period was 679.4 mm (July to January). Similarly, the total rainfall received during 2015-16 was 613.8 mm (40 rainy days) and the rainfall received during cropping period was 468.2 mm (June to December).

Five plants were tagged randomly in net plots for recording growth and yield attributes of crop in different treatments. Yield and yield parameters were recorded periodically till harvest. The price (in rupees) of the inputs and the produce prevailing during the experimental period were considered for working out the economics of the various treatment combinations. Net returns (₹ ha^{-1}) was calculated by deducting the cost of cultivation from gross income (₹ ha^{-1}). The experimental data obtained were subjected to statistical analysis as described by Gomez and Gomez (1984). Statistical analysis of data was done by using MSTAT-C.

Results and discussion

Performance of compact cotton genotypes

Among the genotypes, RAH-274 (116.17 cm and 1.45, respectively), RAH-99 (122.74 cm and 1.51, respectively) and DSC-1351 (128.60 cm and 1.59, respectively) recorded significantly lower plant height and number of monopodial branches per plant as compared to DHG-7-96 (Table 1). These results are supported by Siddiqui *et al.* (2007) who reported that variety CRIS-9 produced taller plants (151.9 cm) followed by Karishma (13 7.2 cm), while Niab-78 produced lowest plant height (127.3 cm). Whereas, number of sympodial branches per plant was significantly higher with RAH-274 (11.95), RAH-99 (11.62) and DSC-1351 (12.27) than DHG-7-96 (Table 1). This might be due to the reason that the higher ability of genotypes in harnessing the solar energy and converting it into biomass and subsequently into reproductive parts such as sympodial branch, flowers and bolls. The difference in number of sympodial branches among varieties might be due to different growth habits and genetic makeup (Asghar *et al.,* 2009).

Significantly higher total dry matter production per plant was recorded with RAH-274 (95.97 g) than other genotypes (Table 1). Similarly, the compact cotton genotype SC-68 recorded significantly higher total dry matter production (54.80 g plant^{-1}) over other genotypes SC-7 and SC-21 at Dharwad (Vinayak, 2006). Whereas, DHG-7-96, RAH-274 and DSC-1351 have registered significantly higher leaf area (39.21, 38.32 and 38.57 dm^2 plant^{-1}, respectively) and leaf area index (6.11, 5.90 and 6.00, respectively) than RAH-99 (Table 1). Dry matter accumulation and distribution in different plant parts depends on photosynthetic ability of the plant which in turn dependence on dry matter accumulation in leaves, stem and reproductive parts, leaf area and leaf area index. However, the dry matter produced per plant alone does not reflect on the efficiency of the genotypes, but its greater partitioning into the reproductive parts is the real index of its effectiveness. This difference was mainly due to genetic makeup and climatic conditions (Siddiqui *et al.,* 2007). However, significantly higher plant spread was recorded with RAH-99 (4,579 cm^2 plant^{-1}) and significantly higher light transmission ratio was obtained with RAH-274 (62.92 %) than other genotypes (Table 2). The differences in the growth parameters among the genotypes were found by Tamilselvam *et al.* (2013) who reported by the robust and compact group mean results revealed that the robust stature of the genotypes (top robust genotypes *viz.,* GTS003, KAV009 and 3366) showed higher plant height (74.58 cm), wider plant diameter (35.18 cm), higher number of monopodial branches per plant (1.50), higher number of sympodial branches per plant (13.97) and LAI per plant (2.30) as compared to compact types. The compact types (top compact types *viz.,* KAV00, KAV002 and KAV004) showed shorter plant height, shorter plant diameter, lower number of monopodial and sympodial branches per plant and LAI (52.93 cm, 30.23 cm, 1.09, 13.54 and 1.69, respectively).

Genotypes differ in their yield potential depending on many physiological processes, which are controlled by both genetic makeup of the plant and the environment. In the present investigation, genotype RAH-274 found superior followed by RAH-99 and DSC-1351 over DHG-7-96 with respect to seed cotton yield and yield components. The significantly higher seed cotton yield was recorded with genotypes RAH-274 (3,199 kg ha^{-1}), RAH-99 (3,156 kg ha^{-1}) and DSC-1351 (3,134 kg ha^{-1}) as compared to DHG-7-96 (2,867 kg ha^{-1}) as shown in Table 3. An increase in the seed cotton yield with RAH-274, RAH-99 and DSC-1351 to an extent of 10.4, 9.2 and 8.5 per cent,

Table 1. Growth parameters of compact cotton genotypes as influenced by planting geometry and fertilizer levels (Pooled data of two years)

Treatments	At harvest				At 120 DAS	
	Plant height (cm)	No. of monopodial branches plant^{1}	No. of sympodial branches plant^{1}	Total dry weight (g plant^{-1})	Leaf area (dm^{2} plant^{-1})	Leaf area index
Genotypes (G)						
G$_1$-RAH-274	116.17^{d}	1.45^{c}	11.95^{ab}	95.97^{a}	38.32^{a}	5.90^{a}
G$_2$-RAH-99	122.74^{c}	1.51^{bc}	11.62^{b}	90.51^{b}	31.89^{b}	4.89^{b}
G$_3$-DHG-7-96	136.97^{a}	1.69^{a}	10.57^{c}	90.98^{b}	39.21^{a}	6.11^{a}
G$_4$-DSC-1351	128.60^{b}	1.59^{ab}	12.27^{a}	89.89^{b}	38.57^{a}	6.00^{a}
S.Em.±	1.45	0.03	0.12	1.01	0.27	0.07
Spacings (S)						
S$_1$-60 × 15 cm	113.13^{c}	1.83^{a}	13.73^{a}	106.28^{a}	43.54^{a}	4.84^{c}
S$_2$-45 × 15 cm	126.31^{b}	1.54^{b}	11.26^{b}	90.38^{b}	35.80^{b}	5.30^{b}
S$_3$-45 × 10 cm	138.91^{a}	1.31^{c}	9.81^{c}	78.86^{c}	31.64^{c}	7.03^{a}
S.Em.±	0.52	0.02	0.05	0.24	0.11	0.02
Fertilizer levels (F) (N, P_2O_5 and K_2O kg ha^{-1})						
F$_1$-80:40:40	121.04^{b}	1.49^{b}	10.94^{b}	87.07^{b}	35.12^{b}	5.46^{b}
F$_2$-100:50:50	131.20^{a}	1.63^{a}	12.26^{a}	96.61^{a}	38.87^{a}	5.99^{a}
S.Em.±	0.39	0.03	0.06	0.55	0.21	0.03
Interactions (G × S × F)						
G$_1$S$_1$F$_1$	99.10^{l}	1.60^{b-e}	12.94^{bc}	104.34^{cd}	42.56^{b}	4.73^{h}
G$_1$S$_1$F$_2$	109.51^{j}	1.80^{a-c}	15.30^{a}	113.90^{a}	48.67^{a}	5.41^{g}
G$_1$S$_2$F$_1$	110.69^{ij}	1.33^{ef}	10.56^{hi}	92.21^{hi}	36.13^{e}	5.35^{g}
G$_1$S$_2$F$_2$	121.31^{f}	1.50^{c-f}	12.46^{cd}	99.08^{d-g}	39.14^{cd}	5.80^{e}
G$_1$S$_3$F$_1$	123.51^{f}	1.17^{f}	9.98^{hi}	79.50^{kl}	30.24^{ij}	6.72^{c}
G$_1$S$_3$F$_2$	132.88^{e}	1.30^{ef}	10.49^{hi}	86.81^{ij}	33.19^{f-g}	7.37^{b}
G$_2$S$_1$F$_1$	103.35^{k}	1.70^{a-d}	12.64^{b-d}	96.54^{e-h}	37.10^{de}	4.12^{j}
G$_2$S$_1$F$_2$	114.34^{hi}	1.83^{a-c}	14.79^{a}	106.91^{bc}	40.79^{bc}	4.53^{hi}
G$_2$S$_2$F$_1$	116.73^{gh}	1.43^{d-f}	10.49^{hi}	84.40^{jk}	28.97^{jk}	4.29^{ij}
G$_2$S$_2$F$_2$	130.35^{e}	1.50^{c-f}	11.76^{d-f}	93.44^{gh}	31.96^{hi}	4.73^{h}
G$_2$S$_3$F$_1$	131.96^{e}	1.23^{f}	9.68^{ij}	77.09^{lm}	24.99^{l}	5.55^{e-g}
G$_2$S$_3$F$_2$	139.73^{c}	1.37^{d-f}	10.35^{hi}	84.72^{jk}	27.51^{k}	6.11^{d}
G$_3$S$_1$F$_1$	116.91^{gh}	1.87^{ab}	11.88^{de}	101.66^{c-e}	40.88^{bc}	4.54^{hi}
G$_3$S$_1$F$_2$	131.40^{e}	2.00^{a}	13.42^{b}	114.62^{a}	49.35^{a}	5.48^{fg}
G$_3$S$_2$F$_1$	132.79^{e}	1.63^{b-e}	10.01^{hi}	83.30^{j-l}	36.36^{e}	5.39^{g}
G$_3$S$_2$F$_2$	141.28^{c}	1.80^{a-c}	10.81^{gh}	95.13^{f-h}	39.20^{cd}	5.81^{e}
G$_3$S$_3$F$_1$	146.02^{b}	1.33^{ef}	8.37^{k}	71.67^{mn}	34.67^{e-g}	7.70^{a}
G$_3$S$_3$F$_2$	153.38^{a}	1.50^{c-f}	8.93^{jk}	79.48^{kl}	34.77^{e-g}	7.73^{a}
G$_4$S$_1$F$_1$	110.30^{ij}	1.83^{a-c}	13.45^{b}	100.38^{d-f}	41.04^{bc}	4.56^{hi}
G$_4$S$_1$F$_2$	120.09^{fg}	1.97^{a}	15.44^{a}	111.85^{ab}	47.94^{a}	5.33^{g}
G$_4$S$_2$F$_1$	122.63^{f}	1.50^{c-f}	11.50^{e-g}	82.53^{j-l}	35.85^{e}	5.31^{g}
G$_4$S$_2$F$_2$	134.72^{de}	1.63^{b-e}	12.52^{b-d}	92.96^{gh}	38.78^{cd}	5.75^{ef}
G$_4$S$_3$F$_1$	138.45^{cd}	1.23^{f}	9.80^{ij}	71.17^{n}	32.62^{gh}	7.25^{b}
G$_4$S$_3$F$_2$	145.39^{b}	1.37^{d-f}	10.90^{f-h}	80.46^{kl}	35.16^{ef}	7.81^{a}
S.Em.±	1.37	0.09	0.29	1.92	0.74	0.11

DAS: Days after sowing, Means followed by the same letter (s) within a column are not significantly differed by DMRT (P=0.05)

respectively over DHG-7-96. This might be due to increased yield parameters, *viz.,* number of bolls per plant and boll weight under RAH-274 (10.37 and 3.01 g, respectively), RAH-99 (10.16 and 3.04g, respectively) and DSC-1351 (10.08 and 3.07g, respectively) were on par with each other and recorded significantly superior over DHG-7-96 (Table 3). The differences in seed cotton yield by the genotypes were reported by Sisodia and Khamparia (2007) and Tuppad (2015). The yielding ability of a genotype is the reflection of its yield attributing characters. The reduction in yield of cotton could be traced back to significant reduction in yield components by genotype DHG-7-96 when compared to other genotypes. Though DHG-7-96 had higher leaf area and LAI resulting in higher total dry matter than RAH-99 and was closer with RAH-274 and DSC-1351, it produced lower yield because of its lower efficiency in converting dry matter into economical produce. Yield is the combined effect of various growth and yield components under particular environmental conditions.

Effect of high density planting geometry on growth and yield parameters

Plant height increased as the row spacing narrowed from 60 x 15 cm to 45 x 10 cm. The highest plant height (138.91 cm) was recorded with narrow spacing of 45 × 10 cm as compared to

Table 2. Plant spread, light transmission ratio and light absorption ratio of compact cotton genotypes as influenced by planting geometry and fertilizer levels (Pooled data of two years)

Treatments	At harvest		
	Plant spread (cm^2 $plant^{-1}$)	Light transmission ratio (%)	Light absorption ratio (%)
Genotypes (G)			
G_1-RAH-274	3620 ^{c}	62.92 ^{a}	37.08 ^{c}
G_2-RAH-99	4579 ^{a}	59.38 ^{b}	40.62 ^{b}
G_3-DHG-7-96	2894 ^{d}	51.41 ^{c}	48.59 ^{a}
G_4-DSC-1351	4010 ^{b}	57.82 ^{b}	42.18 ^{b}
S.Em.±	67.87	0.90	0.90
Spacings (S)			
S_1-60 × 15 cm	4613 ^{a}	63.63 ^{a}	36.37 ^{c}
S_2-45 × 15 cm	3617 ^{b}	58.04 ^{b}	41.96 ^{b}
S_3-45 × 10 cm	3097 ^{c}	51.98 ^{c}	48.02 ^{a}
S.Em.±	28.06	0.81	0.81
Fertilizer levels (F) (N, P_2O_5 and K_2O kg ha^{-1})			
F_1-80:40:40	3537 ^{b}	59.65 ^{a}	40.35 ^{b}
F_2-100:50:50	4015 ^{a}	56.11 ^{b}	43.89 ^{a}
S.Em.±	30.81	0.48	0.48
Interactions (G × S × F)			
$G_1S_1F_1$	4218 ^{de}	69.64 ^{a}	30.36 ^{k}
$G_1S_1F_2$	4743 ^{c}	69.17 ^{ab}	30.83 ^{jk}
$G_1S_2F_1$	3270 ^{j}	67.57 ^{ab}	32.43 ^{jk}
$G_1S_2F_2$	3470 $^{h-j}$	59.03 $^{c-f}$	40.97 $^{f-i}$
$G_1S_3F_1$	2754 ^{kl}	59.09 $^{c-f}$	40.91 $^{f-i}$
$G_1S_3F_2$	3267 ^{j}	53.01 ^{gh}	46.99 ^{de}
$G_2S_1F_1$	4806 ^{c}	66.45 ^{ab}	33.55 ^{jk}
$G_2S_1F_2$	5483 ^{a}	64.50 $^{a-c}$	35.50 $^{i-k}$
$G_2S_2F_1$	4526 ^{cd}	60.87 ^{cd}	39.13 ^{hi}
$G_2S_2F_2$	4782 ^{c}	57.20 $^{d-g}$	42.80 $^{e-h}$
$G_2S_3F_1$	3689 $^{g-i}$	54.71 $^{e-h}$	45.29 $^{d-g}$
$G_2S_3F_2$	4189 ^{e}	52.59 $^{g-i}$	47.41 $^{c-e}$
$G_3S_1F_1$	3637 ^{hi}	58.07 $^{d-g}$	41.93 $^{e-h}$
$G_3S_1F_2$	4116 ^{ef}	57.56 $^{d-g}$	42.44 $^{e-h}$
$G_3S_2F_1$	2532 ^{lm}	54.14 $^{f-h}$	45.86 $^{d-f}$
$G_3S_2F_2$	2916 ^{k}	47.61 $^{i-k}$	52.39 $^{a-c}$
$G_3S_3F_1$	1918 ^{n}	46.71 ^{jk}	53.29 ^{ab}
$G_3S_3F_2$	2241 ^{m}	44.35 ^{k}	55.65 ^{a}
$G_4S_1F_1$	4731 ^{c}	64.16 ^{bc}	35.84 ^{ij}
$G_4S_1F_2$	5168 ^{b}	59.47 $^{c-f}$	40.53 $^{f-i}$
$G_4S_2F_1$	3436 ^{ij}	60.07 $^{c-e}$	39.93 $^{g-i}$
$G_4S_2F_2$	4006 $^{e-g}$	57.85 $^{d-g}$	42.15 $^{e-h}$
$G_4S_3F_1$	2926 ^{k}	54.38 $^{f-h}$	45.62 $^{d-f}$
$G_4S_3F_2$	3795 $^{f-h}$	51.00 $^{h-j}$	49.00 $^{b-d}$
S.Em.±	106.74	1.66	1.66

Means followed by the same letter (s) within a column are not significantly differed by DMRT (P=0.05)

wider spacing of 60 × 15 cm (113.13 cm) (Table 1). These results are in agreement with the results reported by Siddiqui *et al.* (2007) and Tuppad (2015) who reported that closer plant spacing increased the height of the plants. The increase in plant height was because of increased inter plant competition for light, where less space was available for growth of each plant. The increased plant height leads to smaller and thinner stalks leading to lesser stem dry matter per plant at narrow spacing. However, other growth parameters *viz.,* number of monopodial per plant (1.83) and sympodial branches per plant (13.73) and total dry matter production per plant (106.28 g) were significantly higher with wider spacing of 60 × 15 cm than rest of closer spacings (Table 1). The increase in dry matter production per plant was because of reduced inter plant competition as more space was available for growth of individual plant under wider spacing (60 × 15 cm). The similar results of significantly higher total dry matter was obtained by spacing of 60 × 20 cm followed by 60 × 15 cm as compared to rest of closer spacing as reported by Mallikarjun (2013).

Growth parameters help in understanding the importance of morpho-physiological changes during the crop growth and development particularly the economic yield. Total dry matter production and supply of required photosynthates for the developing bolls largely depends on leaf area and leaf area index. The leaf area index 4.84, 5.30 and 7.03 was recorded by the row spacings of 60 x 15 cm, 45 × 15 cm and 45 × 10 cm, respectively (Table 1). The increased LAI was due to more number of plants per unit area there by more number of leaves leads to more LAI. The reduction in leaf area per unit land area at lower plant density or wider spacing because of decreased plant population could not be compensated by increased leaf area per plant. Also, high leaf area index attained by higher plant stand (2,22,222 plants ha^{-1}) might have enabled the crop to intercept higher solar radiation which increased the photosynthetic ability of crop leading to greater biomass production. Generally, increased population levels decreased the plant spread and LTR. Wider spacing of 60 × 15 cm has registered significantly higher plant spread (4,613 cm^2) and LTR (63.63 %) over closer spacings (Table 2). The results were supported by Tuppad (2015) who found that canopy closer occurred more rapidly in closer spacing than in the wider spacing.

The higher population density of 2,22,222 plants ha^{-1} (45 × 10 cm) produced significantly higher seed cotton yield (3,372 kg ha^{-1}) than lower population densities (Table 3). However, the yield attributes like number of sympodial branches per plant, number of bolls per plant and boll weight were recorded significantly higher with wider spacing of 60 × 15 cm (13.73, 11.30 and 3.15 g, respectively) than other spacings (Table 1& 3). Even though decreased yield attributes as plant density increased, may be due to the fact that the increase in plants per unit area could compensated for the decrease in yield components per plant under narrow spacing. This decrease in yield attributes may be due to over population per unit area and more inter plant competition between the plants for light, nutrients and moisture. Sisodia and Khamparia (2007) reported that closer plant density (45 × 45 cm) gave higher yield over 60 × 45 cm and 60 × 60 cm plant spacing. However, these higher values of yield components could not compensate for loss in yield due to lower plant population. Hence, wider spacing of 60 × 15 cm recorded significantly lower yield as compared to closer spacings of 45 × 15 cm and 45 × 10 cm.

Effect of fertilizer levels on growth and yield parameters

Application of higher dose of fertilizer (100:50:50 N, P_2O_5 and K_2O kg ha^{-1}) recorded significantly higher growth parameters

Table 3. Yield parameters, seed cotton yield and economics of compact cotton genotypes as influenced by planting geometry and fertilizer levels (Pooled data of two years)

Treatments	No. of bolls plant^{-1}	No. of good opened bolls plant^{-1}	No. of bad opened bolls plant^{-1}	Boll weight (g)	Seed cotton yield (kg ha^{-1})	Net returns (₹ ha^{-1})
Genotypes (G)						
G_1-RAH-274	10.37 ^{a}	7.85 ^{a}	2.53 ^{b}	3.01 ^{b}	3199 ^{a}	85633 ^{a}
G_2-RAH-99	10.16 ^{a}	7.66 ^{a}	2.50 ^{b}	3.04 ^{ab}	3156 ^{a}	83845 ^{a}
G_3-DHG-7-96	7.81 ^{b}	5.05 ^{b}	2.77 ^{a}	2.92 ^{c}	2867 ^{b}	71694 ^{b}
G_4-DSC-1351	10.08 ^{a}	7.65 ^{a}	2.43 ^{c}	3.07 ^{a}	3134 ^{a}	82899 ^{a}
S.Em.±	0.10	0.11	0.02	0.01	30.9	1299
Spacings (S)						
S_1-60 × 15 cm	11.30 ^{a}	8.49 ^{a}	2.81 ^{a}	3.15 ^{a}	2808 ^{c}	69141 ^{c}
S_2-45 × 15 cm	9.35 ^{b}	6.81 ^{b}	2.54 ^{b}	3.00 ^{b}	3087 ^{b}	80885 ^{b}
S_3-45 × 10 cm	8.17 ^{c}	5.85 ^{c}	2.31 ^{c}	2.88 ^{c}	3372 ^{a}	92678 ^{a}
S.Em.±	0.10	0.10	0.01	0.02	13.9	585
Fertilizer levels (F) (N, P_2O_5 and K_2O kg ha^{-1})						
F_1-80:40:40	9.13 ^{b}	6.50 ^{b}	2.63 ^{a}	2.96 ^{b}	3003 ^{b}	77914 ^{b}
F_2-100:50:50	10.09 ^{a}	7.60 ^{a}	2.49 ^{b}	3.06 ^{a}	3175 ^{a}	84121 ^{a}
S.Em.±	0.08	0.07	0.02	0.02	22.0	926
Interactions (G × S × F)						
$G_1S_1F_1$	11.44 ^{b}	8.59 ^{b}	2.85 ^{bc}	3.10 $^{a-d}$	2810 ^{hi}	70086 ^{hi}
$G_1S_1F_2$	12.74 ^{a}	10.01 ^{a}	2.73 ^{cd}	3.20 ^{ab}	2959 $^{g-i}$	75309 $^{g-i}$
$G_1S_2F_1$	9.79 $^{d-g}$	7.24 ^{de}	2.55 $^{d-g}$	2.89 $^{d-g}$	3055 $^{e-h}$	80055 $^{e-h}$
$G_1S_2F_2$	10.50 $^{c-e}$	8.06 ^{bc}	2.44 $^{g-j}$	3.09 $^{a-e}$	3288 $^{c-e}$	88834 $^{c-e}$
$G_1S_3F_1$	8.49 $^{i-l}$	6.16 $^{f-i}$	2.33 ^{ij}	2.83 ^{fg}	3413 ^{bc}	94911 $^{a-c}$
$G_1S_3F_2$	9.25 $^{f-i}$	7.00 $^{d-f}$	2.25 ^{jk}	2.94 $^{c-g}$	3668 ^{a}	104600 ^{a}
$G_2S_1F_1$	11.10 ^{bc}	8.25 ^{bc}	2.85 ^{bc}	3.10 $^{a-d}$	2815 ^{hi}	70275 $^{g-i}$
$G_2S_1F_2$	12.82 ^{a}	10.14 ^{a}	2.68 $^{c-f}$	3.24 ^{a}	2930 $^{g-i}$	74084 $^{g-i}$
$G_2S_2F_1$	9.17 $^{g-j}$	6.64 $^{e-h}$	2.53 $^{e-i}$	2.98 $^{b-g}$	3003 ^{gh}	77857 $^{f-h}$
$G_2S_2F_2$	10.57 ^{cd}	8.18 ^{bc}	2.39 $^{g-j}$	3.10 $^{a-d}$	3254 $^{c-f}$	87392 $^{c-f}$
$G_2S_3F_1$	8.35 $^{j-l}$	6.01 $^{g-j}$	2.33 ^{ij}	2.88 $^{d-g}$	3362 ^{bc}	92762 ^{bc}
$G_2S_3F_2$	8.99 $^{g-k}$	6.75 $^{e-g}$	2.24 ^{jk}	2.96 $^{c-g}$	3575 ^{ab}	100701 ^{ab}
$G_3S_1F_1$	8.84 $^{h-l}$	5.70 ^{ij}	3.14 ^{a}	3.05 $^{a-f}$	2539 ^{j}	58669 ^{j}
$G_3S_1F_2$	9.72 $^{e-g}$	6.75 $^{e-g}$	2.97 ^{ab}	3.13 $^{a-c}$	2724 ^{ij}	65425 ^{ij}
$G_3S_2F_1$	7.27 ^{m}	4.42 ^{k}	2.85 ^{bc}	2.86 $^{e-g}$	2847 ^{hi}	71305 $^{g-i}$
$G_3S_2F_2$	8.03 ^{l}	5.32 ^{j}	2.71 $^{c-e}$	2.93 $^{c-g}$	2954 $^{g-i}$	74813 $^{g-i}$
$G_3S_3F_1$	6.31 ^{n}	3.78 ^{k}	2.54 $^{d-h}$	2.77 ^{g}	3029 $^{f-h}$	78769 $^{e-h}$
$G_3S_3F_2$	6.72 ^{mn}	4.33 ^{k}	2.39 $^{g-j}$	2.82 ^{fg}	3110 $^{d-g}$	81185 $^{d-g}$
$G_4S_1F_1$	11.13 ^{bc}	8.35 ^{bc}	2.78 ^{bc}	3.15 $^{a-c}$	2810 ^{hi}	70086 ^{hi}
$G_4S_1F_2$	12.64 ^{a}	10.14 ^{a}	2.51 $^{f-i}$	3.26 ^{a}	2880 $^{g-i}$	71991 $^{g-i}$
$G_4S_2F_1$	9.44 $^{f-h}$	7.00 $^{d-f}$	2.44 $^{g-j}$	3.05 $^{a-f}$	3032 $^{f-h}$	79110 $^{e-h}$
$G_4S_2F_2$	10.05 $^{d-f}$	7.64 ^{cd}	2.41 $^{g-j}$	3.14 $^{a-c}$	3262 $^{c-f}$	87714 $^{c-f}$
$G_4S_3F_1$	8.24 ^{kl}	5.90 $^{h-j}$	2.34 $^{h-j}$	2.85 ^{fg}	3322 ^{cd}	91082 $^{b-d}$
$G_4S_3F_2$	9.01 $^{g-k}$	6.90 $^{d-f}$	2.11 ^{k}	2.98 $^{b-g}$	3497 $^{a-c}$	97411 $^{a-c}$
S.Em.±	0.26	0.26	0.06	0.07	76.4	3208

Means followed by the same letter (s) within a column are not significantly differed by DMRT (P=0.05)

viz., plant height (131.20 cm), number of monopodial branches per plant (1.63), number of sympodial branches per plant (12.26), total dry matter production (96.61 g plant^{-1}), leaf area (38.87 dm^2 plant^{-1}), leaf area index (5.99) and plant spread (4,015 cm^2) over lower dose of fertilizer (80:40:40 N, P_2O_5 and K_2O kg ha^{-1}) (Table 1 & 2). The application of lower dose of fertilizer recorded significantly higher LTR (59.65 % at harvest) over higher dose of fertilizer application (Table 2). These results are in line of Zarina *et al.* (2011) who reported that cotton plant height linearly increased with each increment of N from 0 to 150 kg ha^{-1} whereby each higher dose was significantly higher the preceding level.

Seed cotton yield increased with increased levels of fertilizer. The application of higher dose of fertilizer of 100:50:50 N, P_2O_5 and K_2O kg ha^{-1} recorded significantly higher seed cotton yield (3,175 kg ha^{-1}) than lower dose of fertilizer of 80:40:40 N, P_2O_5 and K_2O kg ha^{-1} (3,003 kg ha^{-1}). Improved seed cotton yield was obtained with higher dose of fertilizer due to superior yield attributes *viz.,* number of sympodial branches per plant, number of bolls per plant and mean boll weight (12.26, 10.09 and 3.06 g, respectively) than lower dose of fertilizer (Table 1 & 3). Higher seed cotton yield at higher fertility level might have resulted from the combined effect of nitrogen, phosphorus and potassium applied. This increase in seed cotton yield with increased fertilizer levels is in conformity with the finding of Tuppad (2015). Similarly, increased seed cotton yield with increased N levels was observed by Zarina *et al.* (2011).

Interaction of cotton genotypes, planting geometry and fertilizer levels

Plant height and number of monopodial branches per plant were significantly higher with DHG-7-96 grown at 45 × 10 cm spacing with application of 100:50:50 N, P_2O_5 and K_2O kg ha^{-1} (153.38 cm and 2.00, respectively). However, significantly higher total dry matter production per plant and leaf area were registered by DHG-7-96 at spacing of 60 × 15 cm with application of 100:50:50 N, P_2O_5 and K_2O kg ha^{-1} (114.62 g $plant^{-1}$ and 49.35 dm^2 $plant^{-1}$, respectively) and was on par with RAH-274 and DSC-1351 at same spacing and fertilizer level. Leaf area index was significantly higher with DHG-7-96 grown at 45 × 10 cm spacing with application of 100:50:50 N, P_2O_5 and K_2O kg ha^{-1} (7.73) over other treatments and was on par with RAH-99 and DSC-1351 genotypes each at same spacing and fertilizer level at harvest (Table 1). It was ascribed due to the significantly higher values of leaf area over different growth stages might have helped in capturing and conversion light and carbon dioxide in to photosynthetes resulted in higher dry matter production and translocating photosynthetes into reproductive part. The significantly higher plant spread (5,483 cm^2) was noticed with RAH-99 grown at 60 × 15 cm at 100:50:50 N, P_2O_5 and K_2O kg ha^{-1}. However, maximum light transmission ratio (69.64 %) was observed with RAH-274 sown at 60 × 15 cm with 80:40:40 N, P_2O_5 and K_2O kg ha^{-1} at harvest than rest of treatments. These findings were supported by Sisodia and Khamparia (2007) and Tuppad (2015).

Interaction effect among cotton genotypes, spacing and fertilizer levels, RAH-274 (3668 kg ha^{-1}), RAH-99 (3,575 kg ha^{-1}) and DSC-1351 (3,497 kg ha^{-1}) grown at 45 × 10 cm with application of 100:50:50 N, P_2O_5 and K_2O kg ha^{-1} were recorded on par seed cotton yields and were significantly superior over rest of treatment combinations (Table 3). The differential response of the cotton genotypes in seed cotton due to planting geometry and fertilizer levels can be related to their differential response of growth and yield contributing characters. Treatment combinations of RAH-274, RAH-99 and DSC-1351 grown under spacing of 45 × 10 cm coupled with higher level of fertilizer application (100:50:50 N, P_2O_5 and K_2O kg ha^{-1}) recorded yield components like boll weight (2.94, 2.96 and 2.98 g, respectively) and number of bolls per plant (9.25, 8.99 and 9.01, respectively) (Table 3) and number of sympodial branches per plant (10.49, 10.35 and 10.90, respectively) (Table 1) may be lower than wider spacing, but these treatment combinations increased significantly higher seed cotton yield per hectare might be due to higher plant population per unit area. Irrespective of genotypes the number of bolls and boll weight were increased significantly with increased plant spacing and increased fertilizer level might be due to less competition between the plant and availability of resources. Lower seed cotton yield and seed yield per plant at closer spacing and with lower levels of fertilizer was probably due to less space available for the lateral spread of the plant per unit area which lead to inter plant competition for light, moisture and nutrients. These results are in line with Boquet (2005). Genotype RAH-274, RAH-99 and DSC-1351 performed better under spacing of 45 × 10 cm with higher level of fertilizer application with respect to growth and yield parameters for achieving significantly higher seed cotton yield per hectare over other genotype DHG-7-96, spacings and fertilizer level.

Effect of HDPS on economics of compact cotton genotypes

Pooled analysis data indicated that, RAH-274 was recorded significantly higher net returns (₹ 85,633 ha^{-1}) than DHG-7-96 and was on par with RAH-99 (₹ 83,845 ha^{-1}) and DSC-1351 (₹ 82,899 ha^{-1}) (Table 3). The higher net returns in RAH-274, RAH-99 and DSC-1351 mainly associated with higher seed cotton yield than DHG-7-96. However, Net returns varied significantly due to different spacing levels (population density). The spacing levels 45 × 10 cm (2,22,222 plants ha^{-1}) recorded significantly higher net returns (₹ 92,678 ha^{-1}) and it was followed by 45 × 15 cm (₹ 80,885 ha^{-1}) as compared to wider spacing of 60 × 15 cm and (Table 3). This is mainly because of higher seed cotton yield per hectare. These results are in consonance with findings of Manjunatha *et al.* (2010). There was significant difference in economic analysis of cotton genotypes due to application of different levels of fertilizer. Application of higher levels of fertilizer (100:50:50 N, P_2O_5 and K_2O kg ha^{-1}) recorded significantly higher net returns (₹ 84,121 ha^{-1}) as compared to lower level of fertilizer application of 80:40:40 N, P_2O_5 and K_2O kg ha^{-1} (Table 3). The higher net returns was mainly due to higher economic yield associated with applied higher level of fertilizer treatment. These results are agreement with results of Gadade *et al.* (2012).

Interactions effects between cultivars, plant spacing and fertilizer levels treatments were differed significantly. Significantly higher net returns was recorded with interaction of RAH-274, RAH-99 and DSC-1351 under the spacing of plant spacing of 45 × 10 cm with application of higher dose fertilizer of 100:50:50 N, P_2O_5 and K_2O kg ha^{-1} (₹ 1,04,600, 1,00,701 and 97,411 ha^{-1}, respectively) followed by same systems where lower level of fertilizer applied (Table 3). However, these were significantly superior over remaining treatments. These results are conformity with the results reported by Tuppad (2015) who reported that compact cotton genotypes under high density planty with application of higher dose of fertilizer levels gave higher seed cotton yield and net returns.

Conclusion

Genotypes RAH-274, RAH-99 and DSC-1351 found superior under high density planting system for Northern Transition Zone of Karnataka which produced higher seed cotton yield and net returns They are suitable for machine picking. Combinations of RAH-274, RAH-99 and DSC-1351 each sown at spacing of 45 × 10 cm with the application higher dose of fertilizer of 100:50:50 N, P_2O_5 and K_2O kg ha^{-1} found to be optimum for higher seed cotton yield and net returns under rainfed condition.

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