Indian Journal of Agronomy **59** (3): 385–391 (September 2014)

Research Paper

Productivity potential, quality and economic viability of hybrid Bt cotton (*Gossypium hirsutum*)-based intercropping systems under irrigated conditions

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Received : August 2013; Revised accepted : May 2014

ABSTRACT

A field experiment was conducted during the rainy (*kharif)* season of 2010 and 2011 at Ludhiana, Punjab, to study the effect of different intercrops and row ratio on the growth, yield and quality of hybrid Bt cotton (*Gossypium hirsutum* L.). The number of opened bolls and seed-cotton yield obtained by intercropping Bt cotton with fodder maize [*Zea mays* L., Saccharata), fodder cowpea [*Vigna unguiculata* (L.) Walp.], summer mungbean [*Vigna radiata* (L.) wilczek] and long melon [*Cucumis melo* L. var. *utilissiumus* Duth & Full.] was statistically at par with sole Bt cotton. However, Bt cotton intercropped with fodder pearlmillet or *bajra* [*Pennisetum glaucum* (L.) R. Br. emend. Stuntz] recorded significantly lower number of opened bolls and seed-cotton yield. The Bt cotton, when intercropped with fodder maize in a 1:1 row ratio recorded 43.4% increase in seed-cotton equivalent yield as compared to sole Bt cotton. The seed-cotton equivalent yield obtained from all other intercropping systems except Bt cotton intercropped with fodder pearlmillet in 1:1 and 1:2 row ratios and intercropping of Bt cotton with long melon in 1:2 row ratio recorded significantly higher seed-cotton equivalent yield than sole Bt cotton. Bt cotton when intercropped with long melon showed the highest values of land-equivalent ratio (LER), (1.80) in 1:2 row ratio and area time equivalent ratio (ATER), (1.29) in 1:1 row ratio. The cotton quality parameters like ginning outturn, seed index, lint index, oil percentage and micronaire value were not significantly influenced by intercropping in Bt cotton. However, the fibre strength was significantly reduced by intercropping Bt cotton with fodder maize in 1:1 and 1:2 row ratios, fodder cowpea in 1:1 row ratio and long melon in 1:1 row ratio. The maximum net returns of ₹54,060/ha were obtained when Bt cotton was intercropped with fodder maize 1:1 rows, being 68.6% higher than sole Bt cotton. It was followed by intercropping Bt cotton with fodder maize in1:2 row ratio, which recorded 53.4 % higher returns than sole Bt cotton. Among the different intercropping systems, the maximum benefit: cost ratio (2.47) was also obtained by intercropping Bt cotton with fodder maize in 1:1 row ratio.

Key words **:** Bt cotton, Crop production, Fibre quality, Intercropping, LER, Net returns, Seed cotton yield

Cotton cultivation in India covers an area of approximately 11.8 million ha, representing about one-third of the global area of 34.3 million ha under cotton (www.fas.usda.gov. 2013). The average yield of cotton lint in India is far below the world average of 767 kg/ha and the production is only about 22% of the world production. The introduction of Bt cotton hybrids has given a new hope to the cotton growers as the American bollworm menace was successfully tackled through *Bt* technology. Since the introduction of *Bt* cotton, there has been consistent increase in area under *Bt* cotton year after year. Out of 11.0 m ha area 88% (9.67 m ha) was under Bt cotton hybrids during 2010–11 (AICCIP, 2011). Cotton is also one of the important commercial crops of Punjab and it was grown in about 0.52 m ha with total production of 1.62 m bales during 2012. The average lint yield was 535 kg/ha (PAU, Ludhiana, 2013). Also, the land-holding size of the farmers is shrinking day by day in Punjab. At present, the monetary returns from cotton crop tend to decrease with increased cost of inputs. Hence, there is an urgent need to increase the productivity and profitability per unit area per unit time by adopting suitable cropping system. In different parts of India, work is under progress to develop suitable intercropping systems for different agro-climatic and soil conditions. Since cotton is a widely spaced and initially slow-growing crop, it offers scope for intercropping. The introduction of leguminous intercrops in *Bt* cotton will help maintain the soil-fertility level. Many studies on intercropping have shown increased stability in yields and

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income under intercropping as compared to sole or monocropping under normal or even adverse weather conditions (Singh *et al.,* 2009; Satish *et al.,* 2012). Khan *et al.* (2001) reported that with small reduction in seed-cotton yield, intercrops like fodder maize, fodder cowpea and mungbean can be intercropped with cotton and higher cotton-equivalent yields can be obtained from the intercropping system. Since information on the productivity of different intercrops and their effects on growth and yield of hybrid Bt cotton is not available in Punjab, the present study was conducted to find suitable intercrops for Bt cotton-based intercropping systems under irrigated conditions.

MATERIALS AND METHODS

A field experiment was conducted during rainy (*kharif)* season of 2010 and 2011 at the Punjab Agricultural University, Ludhiana. The soil was loamy sand with normal soil pH (7.9) and electrical conductivity (0.20 dS/m). It was low in organic carbon (0.36%), available N (130.5 kg/ha) and K (121.5 kg/ha) but high in available P (23.6 kg/ha). The total rainfall received during crop-growing season was 661.2 and 1,257.0 mm during 2010 and 2011, respectively, as against the normal rainfall of 733 mm. The treatments comprising combinations of 2 planting geometries of Bt cotton (67.5 cm × 75 cm (1:1) and 135 cm × 37.5 cm (1:2) and 5 intercrops (fodder maize 'J 1006', fodder bajra 'FBC 16', fodder cowpea 'Cowpea 88', summer mungbean 'SML 668' and long melon 'Punjab Longmelon 1'). Bt cotton and different intercrops were also grown as sole for comparison purpose. The experiment was laid out in randomized block design with 4 replications. The Bt cotton hybrid 'RCH 314' was sown by dibbling on a well-prepared seedbed after heavy pre-sowing irrigation on 24 April and 7 May during 2010 and 2011 respectively. Different intercrops, viz. fodder maize, fodder *bajra*, fodder cowpea, summer mungbean and long melon, were also sown on the same day. The recommended dose of fertilizer to Bt cotton (150 kg N and 30 kg P_2O_5/ha) was applied with half dose of nitrogen at thinning and remaining N at the appearance of first flower. Entire dose of phosphorus was applied at the time of sowing. The recommended dose of fertilizer for fodder maize (87.5 kg N, 30 kg P_2O_5 and 20 kg K_2O/ha), fodder *bajra* (50 kg N/ha), fodder cowpea (18.75 kg N and 55 kg P_2O_5/ha), summer mungbean (12.5 kg N, and 40 kg P_2O_5/ha) and long melon (100 kg N, 75 kg P_2O_5 and 50 kg K_2O/ha) were applied on area basis. In fodder maize and *bajra*, half dose of nitrogen and full dose of phosphorus and potassium were applied at the time of sowing and remaining half nitrogen was applied fourth week after sowing. The whole recommended dose of fertilizer for fodder cowpea and summer mungbean was applied at sowing. However, in long melon one-third N, whole P and K were applied at sowing, remaining two-third N was applied in 2 equal splits, i.e. one-third 2 weeks after sowing and one-third 4 weeks after sowing. The total number of irrigations applied was 8 and 5 during 2010 and 2011 respectively. Out of which during intercropping period 6 and 4 irrigations were applied in 2010 and 2011 respectively. Two foliar sprays of potassium nitrate (N: P: K, 13:0:45) were given at weekly interval starting from flower initiation of Bt cotton during both the years. The fodder cowpea was harvested 50 days after sowing (DAS), whereas fodder maize and *bajra* were harvested 60 DAS. The summer mungbean was harvested at physiological maturity (65 DAS) and long melon fruits were picked from 50 to 75 DAS during both the years. The Bt cotton was harvested in 3 pickings from the second fortnight of September to the first fortnight of November. The cotton sticks were uprooted after the last picking on 8 and 4 November during 2010 and 2011 respectively. Seed-cotton equivalent yield (SCEY), land-equivalent ratio (LER), relative yield total (RYT), relative crowding coefficient (RCC), area time equivalent ratio (ATER) and aggressivity were calculated.

The quality parameters (GOT, lint index, seed index) and economics were measured using standard methods. The oil content in cotton seed was determined using Nuclear Magnetic Resonance Spectroscope (NMR). The fibre properties were measured using high volume instrument (HVI).

RESULTS AND DISCUSSION

Performance of Bt cotton

Bt cotton intercropped with fodder maize, fodder cowpea, summer mungbean and long melon recorded growth and yield attributes similar to sole Bt cotton. However, Bt cotton when intercropped with fodder pearlmillet or *bajra* recorded significantly lower values of all the growth and yield attributes (Table 1). Plant height, leaf-area index (LAI), dry matter production, monopodial and sympodial branches/plant and opened bolls/plant of cotton were at par between sole Bt cotton and intercropped Bt cotton except Bt cotton when intercropped with fodder *bajra*. The boll weight did not differ significantly among the various treatments. Further, the planting geometries of 67.5 cm × 75 cm (1:1) and 135 cm × 37.5 cm (1:2) did not significantly influence the growth and yield attributes of Bt cotton. The seed-cotton yield varied significantly under different intercropping systems. The maximum seed-cotton yield was recorded in Bt cotton intercropped with long melon in 1:1 row ratio (Table 2). The seed-cotton yield was at par among all the intercropping systems except Bt cotton intercropped with fodder *bajra* in1:1 and 1:2 row

ratios. Intercropping Bt cotton with fodder *bajra* in 1:1 row ratio recorded the highest reduction of seed-cotton yield which was 45.5% as compared to sole Bt cotton. Thus, the results showed that all the intercrops except fodder *bajra* had no adverse effect on the growth and yield of Bt cotton. Various growth and yield-contributing characters like plant height, leaf-area index, monopodial branches, sympodial branches and bolls/plant were significantly reduced in Bt cotton when intercropped with fodder *bajra* which eventually decreased the seed-cotton yield significantly. This was attributed to fast growing and tillering nature of *bajra,* which influenced the growth and development of Bt cotton by posing severe competition for all the growth resources, viz. light, nutrients, space and moisture. However, fodder maize did not significantly affect the seed-cotton yield due to its erect growth habit, which caused less hindrance to Bt cotton for light interception. Summer mungbean and fodder cowpea as intercrops showed synergistic effect on Bt cotton yield by fixing atmospheric nitrogen and provided better nutrition to the cotton plants. Similarly, Marshal and Willey (1983) reported that intercropping pearl millet with groundnut, pearl millet intercepted 2.1 times more photosynthetically active radiation (PAR) in intercrop than in monocrop and used it with similar efficiency to produce twice as much dry matter. While groundnut growing at lower layer of the canopy received 27% less PAR interception. Also, Nagre (1979) and Khan *et al.* (2001) reported that intercropping systems like cotton + mungbean, cotton + cowpea fodder and cotton + maize fodder caused smaller reduction in the seed-cotton yield as compared to sole cotton, while severe reduction in seed-cotton yield was recorded under cotton + sesame intercropping system.

Performance of intercrops

The performance of intercrops was altered with intercropping in cotton. The results showed that sole maize crop gave the green fodder yield of 39.59 t/ha, while maize intercropped with Bt cotton in 1:1 planting geometry gave the 61.9% of sole crop yield and maize planted with 1:2 planting geometry gave the 51.9% green fodder yield of sole crop yield. *Bajra* green fodder yield of 48.70 t/ha was obtained from sole planted crop. Intercropping of *bajra* with cotton in 1:1 row planting geometry produced 65.1%, while in 1:2 planting geometry provided 54.2% of sole crop yield. From the sole crop of cowpea, green fodder yield of 24.12 t/ha was obtained. Intercropping of Bt cotton with cowpea in 1:1 row planting geometry gave 69.2% green fodder yield of the sole crop, while in 1:2 row planting geometry it showed 65.1%. Sole summer mungbean recorded grain yield of 0.75 t/ha. The intercropping of summer mungbean in Bt cotton with 1:1 planting geometry gave 58.7% grain yield and with 1:2 planting geometry it was 41.3% of the sole crop. The lower grain yield of summer mungbean was because of more rainfall during the second crop season, which resulted in excessive vegetative growth and poor pod development. The long melon provided fruit yield of 1.51 t/ha under sole planting, while in 1:1 planting geometry it gave fruit yield of 1.10 t/ha and with 1:2 planting geometry it was 1.24 t/ha. A small reduction in yield of long melon might be due the equal plant population of the intercrop as compared to sole crop plant population.

Table 1. Growth and yield attributes of Bt cotton as influenced by different intercropping systems in relation to planting geometries (pooled data of 2 years)

Intercropping system	Plant height (cm)	Leaf-area index (120 DAS)	Dry matter at 150 DAS (t/ha)	Monopodial branches/ plant	Sympodial branches/ plant	Opened bolls/plant	Boll weight (g)
Bt cotton + fodder maize (1:1)	102.5	3.43	4.91	2.7	19.5	29.9	3.64
Bt cotton + fodder *bajra* (1:1)	77.8	2.20	2.90	1.5	12.7	19.7	3.56
Bt cotton + fodder cowpea (1:1)	96.7	3.41	4.90	2.7	19.5	30.0	3.62
Bt cotton + summer mungbean (1:1)	107.7	3.36	5.22	2.7	20.8	32.1	3.69
Bt cotton + long melon (1:1)	103.1	3.87	5.29	3.0	21.4	33.3	3.74
Bt cotton + fodder maize (1:2)	104.0	3.51	4.91	2.7	19.5	29.6	3.63
Bt cotton + fodder *bajra* (1:2)	80.3	2.16	2.99	1.5	12.3	20.0	3.43
Bt cotton + fodder cowpea (1:2)	104.1	3.57	5.16	2.7	20.5	32.1	3.53
Bt cotton + summer mungbean (1:2)	106.9	3.82	5.18	2.7	20.9	31.8	3.59
Bt cotton + long melon (1:2)	102.6	3.73	5.12	2.8	20.7	31.2	3.68
Sole Bt cotton	101.5	3.90	5.23	3.0	21.2	32.0	3.76
SEm±	4.12	0.27	0.12	0.15	0.77	1.99	0.11
CD (P=0.05)	8.25	0.55	0.25	0.30	1.55	4.00	NS

DAS, Days after sowing

Seed-cotton equivalent yield

Among the different intercropping systems, Bt cotton intercropped with fodder maize in 1:1 row ratio recorded the maximum seed-cotton equivalent yield and it was statistically at par with Bt cotton intercropped with fodder maize in 1:2 row ratio, but was significantly superior to all other intercropping systems and sole Bt cotton. However, Bt cotton intercropped with fodder cowpea in 1:1 and 1:2 row ratios and Bt cotton + summer mungbean 1:1 and 1:2 row ratios and Bt cotton + long melon in 1:1 row ratio recorded significantly superior seed-cotton equivalent yield than sole Bt cotton. Among the intercropping systems, the lowest seed-cotton equivalent yield was recorded from Bt cotton when it intercropped with fodder *bajra* in 1:2 planting geometry. The different intercropping systems, viz. Bt cotton + fodder maize (1:1), Bt cotton + fodder maize (1:2), Bt cotton + fodder cowpea (1:2), Bt cotton + fodder cowpea (1:1), Bt cotton + summer mungbean (1:1) and Bt cotton + summer mungbean (1:2) showed 43.4, 34.5, 31.9, 25.6, 21.5 and 16.2% increase in seed-cotton equivalent yield over sole Bt cotton. Further, Bt cotton intercropped with long melon in 1:1 and 1:2 row ratios and Bt cotton + fodder *bajra* in 1:1 row ratio also recorded 12.0, 8.4 and 6.8% increase in seed-cotton equivalent yield over sole Bt cotton. Similarly, Balasubramanian *et al.* (1994) and Chellaiah and Gopalaswamy (2000) reported that cotton intercropped with blackgram, greengram, soybean or mash bean gave significantly higher seed-cotton equivalent yield than sole cotton.

Competition indices

The LER and ATER are important indices to measure the yield advantage in intercropping system. Different intercropping systems varied significantly in respect of LER and ATER (Table 3). All the intercropping systems, recorded higher LER than sole Bt cotton. Similarly, all the intercropping systems also recorded higher ATER except Bt cotton intercropped with fodder *bajra* in 1:1 and 1:2 row ratios, indicating advantage of intercropping over sole Bt cotton. The maximum LER was recorded from Bt cotton intercropped with long melon in 1:2 row ratio and maximum ATER from Bt cotton intercropped with long melon in 1:1 row ratio. Ganajaxi *et al.* (2011) also reported higher LER under intercropping in Bt cotton than sole cotton. In relative yield total (RYT), yield advantages are measured not only on the basis of unit area, but also on the basis of unit population. The highest RYT was recorded from Bt cotton intercropped with summer mungbean in 1:1 row ratio, followed by Bt cotton + fodder bajra in1:1 row ratio and Bt cotton + fodder cowpea in

Table 2. Effect of different intercropping systems on intercrop yield, seed cotton yield, seed-cotton equivalent yield and economics (pooled data of 2 years)

Intercropping system	Intercrop yield (t/ha)	Seed-cotton yield (t/ha)	Seed-cotton equivalent yield (t/ha)	Gross returns (×10^3 ₹/ha)	Net returns (×10^3₹/ha)	Benefit: cost ratio
Bt cotton + fodder maize (1:1)	24.51	1.75	2.74	90.70	54.06	2.47
Bt cotton + fodder *bajra* (1:1)	31.72	1.04	2.04	66.74	36.24	2.19
Bt cotton + fodder cowpea (1:1)	16.70	1.72	2.40	79.64	44.20	2.24
Bt cotton + summer mungbean (1:1)	0.44	1.87	2.32	78.29	41.26	2.14
Bt cotton + long melon (1:1)	1.10	1.96	2.14	71.87	33.44	1.86
Bt cotton + fodder maize (1:2)	20.55	1.74	2.57	85.09	49.19	2.36
Bt cotton + fodder *bajra* (1:2)	26.38	1.05	1.89	61.75	31.16	2.02
Bt cotton + fodder cowpea (1:2)	15.71	1.88	2.52	84.11	47.34	2.28
Bt cotton + summer mungbean (1:2)	0.31	1.88	2.22	74.82	37.31	1.98
Bt cotton + long melon (1:2)	1.24	1.87	2.07	69.82	31.47	1.80
Sole Bt cotton	0.00	1.91	1.91	65.13	32.07	1.95
Sole fodder maize	39.59	–	1.60	50.51	30.40	2.51
Sole fodder *bajra*	48.70	–	1.55	48.70	32.76	3.06
Sole fodder cowpea	24.12	–	0.98	30.80	10.75	1.54
Sole summer mungbean	0.75	–	0.80	26.05	8.99	1.53
Sole long melon	1.51	–	0.24	7.53	-4.75	0.61
SEm±	1.22	0.12	0.11	3.67	3.67	0.11
CD (P=0.05)	2.43	0.24	0.22	7.29	7.29	0.21

Selling price (2010) Bt cotton ₹30,000/t; fodder maize ₹1,250/t; fodder *bajra* ₹1,000/t; fodder cowpea ₹1,250/t; summer mungbean ₹31,700/t; long melon ₹5,000/t; cotton sticks ₹900/t.
Selling price (2011) Bt cotton ₹33,000/t; fodder maize ₹1,300/t; fodder *bajra* ₹1,000/t; fodder cowpea ₹1,300/t; summer mungbean ₹35,000/t ; long melon ₹5,000/t; cotton sticks ₹1,000/t.

1:1 row ratio. The higher RYT obtained in Bt cotton + fodder *bajra* intercropping system can be attributed to tillering nature of *bajra* crop. The relative crowding coefficient is an index which is based on the plant density of each crop in the intercropping system. The product of RCC (K) should be more than 1 for the system to be advantageous. All the intercropping systems except Bt cotton intercropped with fodder *bajra* recorded product of K greater than 1; indicating that intercropping systems were advantageous, but in fodder *bajra* the product of K was less than 1, indicating disadvantage of the mixture. It may be due to tillering habit of fodder *bajra* that Bt cotton faced adverse effect of intercrop like shading, severe root competition resulting in stunted growth and less yield of seed-cotton. The aggressivity value of –1.42 in Bt cotton intercropped with fodder *bajra* in 1:1 row ratio indicated that Bt cotton was dominated by fodder *bajra*. The greater numerical values indicated bigger the difference in competitive abilities of these crops and larger the difference between actual and expected yields. Further, it was observed that aggressivity values were lower in Bt cotton + fodder *bajra* 1:2 planting geometry which were –1.09, which may be attributed to less shading effect of fodder *bajra* on Bt cotton under this planting geometry. This indicated that in 1:2 planting geometry, where 2 rows of fodder *bajra* were planted at 22 cm apart between 2 rows of Bt cotton spaced 135 cm apart, fodder *bajra* was less dominant over Bt cotton. This may be because of intra competition of fodder *bajra* for space, nutrients and water from a limited space and it is a well known fact that *intra*-competition is more severe than inter competition. Bt cotton intercropped with long melon in 1:2 row ratio recorded the lowest values of aggressivity. The crops like summer mungbean, fodder cowpea and fodder maize recorded intermediate values of aggressivity less than 1, thus were suitable for intercropping.

Quality of Bt cotton

Ginning outturn, is an important quality character which influences the price of cotton in the market, indicates the amount of lint present in seed cotton. Different intercropping systems had no significant influence on ginning outturn; however, all the intercropping systems showed numerically lower values of ginning percentage than sole Bt cotton (Table 4). Similarly, Sethi *et al.* (1992) and Mukherji and Verma (1994) reported that different intercrops did not show any adverse effect on the ginning (%). A lower value of seed index (100-seed weight in g) indicates more immature seeds which deteriorates the industrial value of the cotton seed. Seed index did not vary significantly with the different intercropping systems in both the years. The higher values of seed index were recorded in sole *Bt* cotton; however, the lower values for seed index were recorded in *Bt* cotton intercropped with fodder *bajra* in 1:2 and 1:1 row ratio. Lint index is a measure of surface area and density of fibre on the seed. It is directly related to seed index and ginning outturn. The various intercropping systems recorded non-significant differences in the lint index. However, numerically higher values of lint index were recorded in sole Bt cotton, whereas the lowest values of lint index were recorded from Bt cotton intercropped with fodder maize in 1:1 row ratio. Oil percentage in cotton seed is very important from industrial point of view. The different intercropping systems influence significantly the oil content in the seeds of *Bt* cotton. The highest values of oil content were recorded from sole *Bt* cotton (20.1%), which was significantly superior to cotton intercropped with fodder maize in 1:1 and

Table 3. Effect of different intercropping systems on land-equivalent ratio, relative yield total and relative crowding coefficient, aggressivity and area-time equivalent ratio (pooled data of 2 years).

Intercropping system	Land-equivalent ratio	Relative yield total	Relative crowding coefficient(K)	Aggressivity		Area-time equivalent ratio
				Ac	Ai	
Bt cotton + fodder maize (1:1)	1.55	2.33	15.24	–0.49	0.49	1.13
Bt cotton + fodder *bajra* (1:1)	1.18	2.71	0.42	–1.42	1.42	0.76
Bt cotton + fodder cowpea (1:1)	1.60	2.48	20.02	–0.69	0.69	1.09
Bt cotton + summer mungbean (1:1)	1.63	3.09	16.03	–0.93	0.93	1.21
Bt cotton + long melon (1:1)	1.75	1.76	193.45	0.31	-0.31	1.29
Bt cotton + fodder maize (1:2)	1.46	2.10	7.15	–0.26	0.26	1.09
Bt cotton + fodder *bajra* (1:2)	1.09	2.34	0.31	–1.09	1.09	0.72
Bt cotton + fodder cowpea (1:2)	1.63	2.46	7.17	–0.52	0.52	1.16
Bt cotton + summer mungbean (1:2)	1.44	2.43	6.04	–0.45	0.45	1.14
Bt cotton + long melon (1:2)	1.80	1.81	380.30	0.15	-0.15	1.27
Sole Bt cotton	1.00	1.00	–	–	–	1.00

Ac, Aggressivity of cotton over intercrop; Ai, aggressivity of intercrop over cotton

1:2 rows, *Bt* cotton + fodder *bajra* in 1:1 and 1:2 row ratios and Bt cotton intercropped with summer mungbean in 1:2 row ratio and it was statistically at par with all other intercropping systems.

Fibre quality parameters

The maximum 2.5% span length (Table 5) was recorded in Bt cotton intercropped with fodder *bajra* in 1:2 row ratio, being significantly superior to Bt cotton intercropped with summer mungbean in 1:1 and 1:2 planting geometries and Bt cotton intercropped with long melon in 1:1 row ratio and it was statistically at par with all other intercropping systems as well as sole Bt cotton. The maximum bundle strength was recorded in Bt cotton intercropped with fodder *bajra* in 1:2 row ratio which was significantly reduced by intercropping Bt cotton with fodder maize in 1:1 and 1:2 planting geometries and Bt cotton intercropped with fodder cowpea in 1:1 row ratio and Bt cotton intercropped with long melon in 1:1 row ratio, but all other intercropping systems recorded bundle strength at par with sole Bt cotton. The fibre fineness or micronaire values were not significantly influenced by different intercropping systems compared to sole Bt cotton. The micronaire values ranged from 3.0 to 4.0, fibre was in the fine category. The fibre maturity observed in sole Bt cotton was maximum (0.87) and significantly superior to Bt cotton intercropped with fodder maize in 1:1 and 1:2 row ratios and Bt cotton intercropped with fodder *bajra* in 1:2 row ratio, but it was statistically at par with all other intercropping systems. The maximum uniformity ratio was observed in sole Bt cotton, which was significantly higher than Bt cotton intercropped with fodder maize in 1:1 and 1:2 row ratios, Bt cotton intercropped with summer mungbean in 1:1 and 1:2 row ratio and Bt cotton intercropped with long melon in 1:1 planting geometry. But, it was statistically at par with all other intercropping systems. The maximum fibre elongation percentage was recorded with sole Bt cotton which was significantly better

Table 4. Effect of different intercropping systems on ginning outturn, seed index, lint index and oil content in seeds of Bt cotton (pooled data of 2 years)

Intercropping system	GOT (%)	Seed index (g)	Lint index	Oil content (%)
Bt cotton + fodder maize (1:1)	34.4	8.03	4.21	18.2
Bt cotton + fodder *bajra* (1:1)	34.9	7.91	4.25	17.4
Bt cotton + fodder cowpea (1:1)	34.6	8.01	4.25	18.9
Bt cotton + summer mungbean (1:1)	34.7	8.10	4.30	18.9
Bt cotton + long melon (1:1)	34.6	8.19	4.34	19.4
Bt cotton + fodder maize (1:2)	34.9	7.96	4.27	17.6
Bt cotton + fodder *bajra* (1:2)	34.6	7.88	4.22	16.9
Bt cotton + fodder cowpea (1:2)	34.6	8.07	4.26	18.8
Bt cotton + summer mungbean (1:2)	34.8	7.99	4.26	18.1
Bt cotton + long melon (1:2)	34.8	8.04	4.29	18.7
Sole Bt cotton	35.1	8.30	4.49	20.1
SEm±	0.88	0.28	0.22	0.70
CD (P=0.05)	NS	NS	NS	1.41

Table 5. Effect of intercropping systems and planting geometry on the fibre quality of Bt cotton.

Intercropping system	2.5% span length	Strength (g/tex)	Micronaire (µg/inch)	Maturity ratio	Uniformity ratio (%)	Elongation (%)	Short fibre index
Bt cotton + fodder maize (1:1)	29.91	22.00	3.43	0.85	44.39	5.24	6.48
Bt cotton + fodder *bajra* (1:1)	30.36	22.84	3.54	0.86	45.32	5.39	4.74
Bt cotton + fodder cowpea (1:1)	30.06	21.50	3.67	0.86	45.07	5.26	5.48
Bt cotton + summer mungbean (1:1)	29.13	22.85	3.50	0.86	45.36	5.26	6.44
Bt cotton + long melon (1:1)	29.12	22.42	3.79	0.87	45.38	5.30	6.41
Bt cotton + fodder maize (1:2)	29.62	21.80	3.29	0.84	44.72	5.22	6.28
Bt cotton + fodder *bajra* (1:2)	30.50	24.19	3.21	0.85	45.47	5.37	4.41
Bt cotton + fodder cowpea (1:2)	30.06	23.48	3.73	0.87	45.16	5.36	5.22
Bt cotton + summer mungbean (1:2)	29.14	23.18	3.49	0.87	45.47	5.34	6.81
Bt cotton + long melon (1:2)	29.95	22.74	3.52	0.86	44.85	5.34	5.60
Sole Bt cotton	30.03	24.07	3.68	0.87	45.54	5.42	4.96
SEm±	0.323	0.524	0.137	0.006	0.200	0.033	0.387
CD (P=0.05)	0.93	1.51	NS	0.02	0.58	0.09	1.12

than Bt cotton + fodder maize (1:1 and 1:2), Bt cotton + fodder cowpea (1:1), Bt cotton + long melon (1:1) and Bt cotton + summer mungbean (1:1) intercropping systems; however, it was statistically at par with all other intercropping systems. The short fibre index recorded lower values in Bt cotton + fodder *bajra* (1:1 and 1:2) and sole Bt cotton. This may be because in these intercropping systems, cotton bolls were formed early in the season which developed fibre of full length. The sole Bt cotton recorded short fibre index at par with Bt cotton + fodder cowpea (1:1 and 1:2) and Bt cotton + long melon (1:2). All the other intercropping systems recorded higher values of short fibre index. Sethi *et al.* (1992) also reported that fibre quality parameters were not influenced by intercropping of cotton with groundnut and mungbean.

Economic viability

The Bt cotton intercropped with fodder maize in 1:1 row ratio gave the maximum gross and net returns (Table 2). This intercropping system was statistically at par with Bt cotton intercropped with fodder maize in 1:2 row ratio, Bt cotton intercropped with fodder cowpea in 1:1 and 1:2 row ratios and Bt cotton intercropped with summer mungbean in1:1 row ratio but were significantly higher than the sole Bt cotton. Among the intercropping systems, the lowest gross returns and net returns were obtained from Bt cotton intercropped with fodder *bajra* in 1:2 row ratio. Chellamuthu and Ramaswami (2000) also reported that cotton + cowpea, cotton + black gram, cotton + greengram and cotton + soybean recorded significantly higher gross and net returns than the sole cotton. Among different intercropping systems, the Bt cotton intercropped with fodder maize in 1:1 row ratio recorded maximum benefit cost ratio of 2.47, which was statistically at par with Bt cotton intercropped with fodder maize in 1:2 row ratio and Bt cotton intercropped with fodder cowpea in 1:2 row ratio. In addition to above Bt cotton intercropped with fodder *bajra* in 1:1 row ratio and Bt cotton intercropped with fodder cowpea in 1:1 row ratio was significantly superior for benefit: cost ratio to sole Bt cotton. Among all the intercropping systems, Bt cotton intercropped with long melon in 1:2 row ratio recorded lowest benefit: cost ratio. Similarly, Chellamuthu and Ramaswami (2000) and Chellaiah and Gopalaswamy (2000) observed that intercropping systems, viz. cotton + cowpea, cotton + blackgram, cotton + greengram and cotton + soybean, recorded significantly higher benefit: cost ratio than sole Bt cotton.

Therefore, it can be concluded that based on seed-cotton equivalent yield and economic returns obtained from the Bt cotton-based intercropping systems, intercropping of Bt cotton with fodder maize in 1:1 and 1:2 row ratios and Bt cotton + fodder cowpea in 1:1 or 1:2 row ratios were found to be superior to sole Bt cotton. The quality parameters of Bt cotton were not influenced by different intercropping systems except fibre strength.

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