International Journal of Food, Agriculture and Veterinary Sciences ISSN: 2277-209X (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jfav.htm
2015 Vol. 5 (3) September-December, pp. 99-112/Jayalalitha et al.
Research Article

EFFECT OF WATER STRESS ON MORPHOLOGICAL, PHYSIOLOGICAL PARAMETERS AND SEED COTTON YIELD OF *BT* COTTON *(GOSSYPIUM HIRSUTUM* L.) HYBRIDS

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ABSTRACT
Twelve *Bt* cotton hybrids were evaluated under rainfed condition (moisture stress) for morpho–physiological characters and seed cotton yield in a field experiment conducted during Kharif 2009 -10 and 2010-11. Significant differences were observed between main treatments viz., no stress (irrigation treatment) and stress (rainfed treatment) and sub treatments (12 *Bt* cotton hybrids) and their interactions with regards to morphological parameters such as plant height, number of sympodia plant–1, days to 50% flowering and days to 50% boll bursting; physiological parameters viz., leaf area and total dry matter production and seed cotton yield in both the years. Cotton hybrids under rainfed condition (moisture stress) recorded 15 and 18 per cent reduction in plant height and 31.6 and 32.9 per cent reduction in mean number of sympodia per plant at harvest compared to irrigated condition (no stress) in both the years respectively. The number of days taken to 50 per cent flowering was significantly lower (59.28 days) under rainfed condition compared to irrigated condition (68.53 days) during 2009-10. *Bt* cotton hybrids, under rainfed condition attained early boll opening by about 15.89 days and 14.92 days in both the years respectively compared to irrigated condition. Total leaf area and dry matter production were found to be decreased at peak flowering and boll development stages under rainfed condition in both the years of study. Seed cotton yield was decreased by 39.3 per cent (1634.44 kg ha -1 during 2009-10) and 25.6 per cent (1849.01 kg ha -1 during 2010-11) in rainfed plots compared to irrigated plots (2693.52 kg ha -1 during 2009-10 and 2486.10 kg ha -1 during 2010-11). Among the *Bt* cotton hybrids tested, Tulasi 9 BG –II, Tulasi 9 BG –I and Bunny BG-I recorded higher number of sympodia plant -1, leaf area, total dry matter and seed cotton yield both under irrigated as well as rainfed conditions. These hybrids also took more number of days to 50% flowering and 50% boll opening in both the years, where as Jk Durga BG-I, Rasi Early BG-I and BG-II recorded lower values for all the above parameters, under both the conditions. Hence, the current study concluded with the remarks that the *Bt* cotton hybrids Tulasi 9 BG –I, BG –II and Bunny BG – I are drought resistant while Jk Durga BG-I, Rasi Early BG-I and BG-II are drought prone hybrids.

Keywords: *Bt Cotton, Rainfed, Moisture Stress, Leaf Area, Dry Matter, Sympodia, Seed Cotton Yield*

INTRODUCTION
Globally cotton is being cultivated in an area of 31.74 m ha in about 80 countries. It is a premier cash crop in India and plays an important role in the economy of the country. It sustains the country`s cotton textile industry which is the largest segment of organized industries of the country. India earns foreign exchange from export of cotton yarn, thread, fabrics, apparel and made ups. It has an enormous potential of sustaining employment generation and economic cum trade activity. Nearly 1/3 of the country`s export earning is from the textile sector, of which cotton accounts for 65% of the raw material.
Drought is an important and major abiotic stress affecting the productivity of all the rainfed crops. Even though cotton is a drought tolerant crop, it responds well to sufficient water by producing lint proportional to amounts of rainfall or irrigation supplied. Each season, cotton uses approximately 21 to 38 acre-inches of moisture. Timely rainfall early in the season establishes crop stand and in the summer months it sustains squaring, flowering and bolls even beyond that normal 40 to 50 per cent of fruiting structures.
Drought stress results in photosynthetic reduction, which arises by a decrease in leaf expansion, impairs photosynthetic apparatus, dry matter production and associated decrease in food production (Wahid &

Rasul, 2005). Development of crops for improved drought resistance entails the understanding of physiological mechanisms and genetic control of the contributing characteristics at different plant developmental stages.

In Andhra Pradesh 80 per cent of cotton is being cultivated under rainfed conditions. Apart from irrigated areas, *Bt* cotton hybrids are being extensively grown under rainfed conditions. Under rainfed conditions, during the years of low rainfall, performance of *Bt* cotton hybrids reported to be poor, compared to their performance under irrigated conditions. Though abundant research was carried out on the effects of moisture stress on non *Bt* cotton hybrids, information on performance of these BG-I and BG-II hybrids under moisture stress or rainfed is scanty. Hence, generating information on morpho-physiological and yield attributes of *Bt* cotton hybrids under rainfed conditions is a research priority. Keeping this in view, the present investigation was taken up with popular *Bt* cotton hybrids in Andhra Pradesh.

MATERIALS AND METHODS

The present investigation was undertaken at Agricultural college farm, Bapatla during two consecutive years of *kharif* 2009-10 and 2010-11. The treatments comprised two main plots i.e., no stress (i.e., irrigation is given as per irrigation schedule) and stress (i.e., rainfed condition) and twelve *Bt* cotton hybrids as sub plots viz., Bunny BG-I, Bunny BG- II, Kisan Early BG-I, Kisan Early BG-II, RCH2 BG-I, RCH2 BG-II, Rasi Early BG-I, Rasi Early BG-II, Tulasi 9 BG-I, Tulasi 9 BG- II, JK Durga BG-I and RCH 138 BG-I. The experiment was laid out in a strip plot design with three replications.

Seeds of *Bt* cotton hybrids were sown on 17-08-2009 and on 23-08-2010. Each hybrid was grown in 7 rows of 4.2 meters length with a spacing of 105 cm between rows and 60 cm within the rows. Single super phosphate @ 60 kg P2 O5 ha -1was applied as basal fertilizer. N and K were applied @ 120 and 60 Kg ha-1 in three equal split doses at 30, 60 and 90 days after sowing. Prophylactic measures were taken up regularly to prevent the incidence of pests, diseases and weeds. For rainfed treatment, no irrigation was given at any stage of plant growth. For irrigated treatment, irrigation was given as per irrigation schedule. During *kharif* 2009-10, crop received a total rainfall of 604.7 mm in 23 rainy days. There was one dry spell at vegetative phase and one dry spell at squaring stage. However, moisture sensitive growth period i.e., squaring to peak flowering suffered with continuous three dry spells (36 days). Similarly, boll development to maturity stage exposed to continuous four dry spells. During *kharif* 2010-11, crop received a total rain fall of 986.5 mm in 33 rainy days and the crop experienced comparatively less moisture stress before peak flowering stage. However, boll development phase exposed to one dry spell and boll maturity phase exposed to prolonged six dry spells.

Five representative samples were selected in each treatment and tagged with wax coated labels and the data on morphological parameters such as plant height, number of sympodia plant -1, days to 50% flowering and days to 50% boll bursting were recorded. The data on physiological parameters such as leaf area and total dry matter were recorded from destructive sampling of *Bt* cotton hybrids at peak flowering and boll development stages. Data on seed cotton yield were recorded at harvest. The data were analyzed statistically following analysis of variance (ANOVA) technique suggested by Panse and Sukhathme (1978) for strip plot design. Statistical significance was tested by `F` value at 5 per cent level of probability.

RESULTS AND DISCUSSION

Morphological Parameters

Plant Height (cm)

The plant height as influenced by water stress at boll maturity stage among *Bt* cotton hybrids is presented in table 1. Plant height increased from vegetative stage (30 DAS) to boll maturity stage (135 DAS) irrespective of treatments and hybrids, however, the increase was exponential from 45 to 75 DAS in both the years. Significant differences were observed between main treatments and cotton hybrids with regards to plant height at different growth stages in both the years but the interaction was non-significant. The mean plant height of cotton hybrids was significantly lower under rainfed condition compared to irrigated

condition in both the years of study. Cotton hybrids under rainfed condition recorded 15.0 and 18.0% reduction at boll maturity stage compared to irrigated condition in both the years respectively. Similar reduction in plant height (38.3%) was reported in cotton hybrids under severe moisture stress (Ninganur *et al.,* 2008). Hearn (1979) reported that in cotton the processes dependent on cell expansion i.e. plant height is more sensitive to water deficits than the processes associated with stomatal closure.

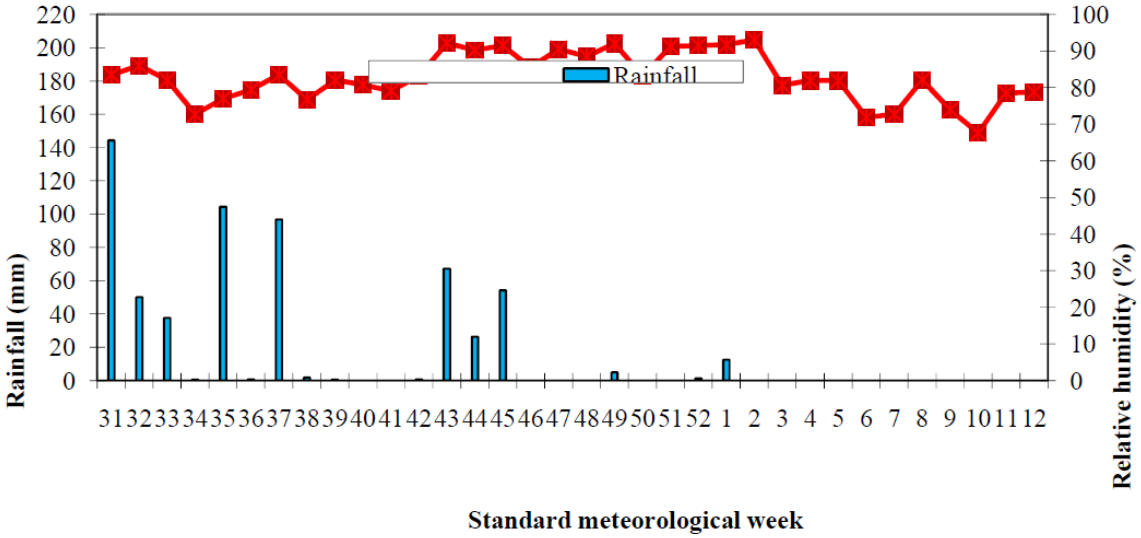

Figure 1: Weekly mean relative humidity and rainfall during the crop growth period, 2009-10

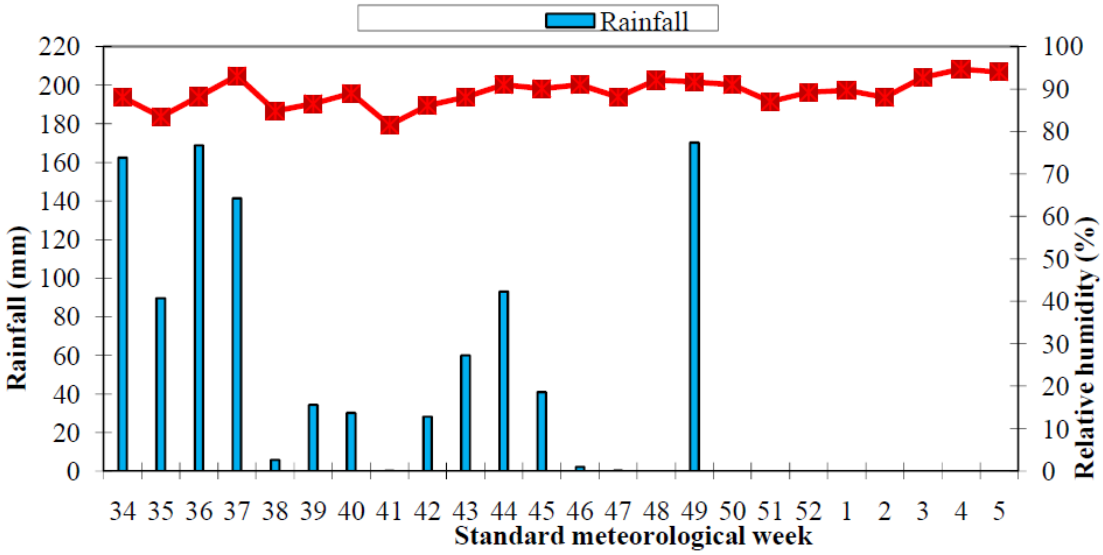

Figure 2: Weekly mean relative humidity and rainfall during the crop growth period, 2010-11

At boll maturity stage, among the cotton hybrids tested, RCH2 BG-I recorded highest plant height (125.60cm during 2009-10 and 116.45cm during 2010-11) followed by Rasi Early BG-I (125.33 cm during 2009-10), Rasi Early BG-II (114.15 cm during 2010-11), Rasi Early BG-II (124.80 cm during 2009-10), Rasi Early BG-I (113.75cm during 2010-11) and Tulasi 9 BG-II (121.23cm during 2009-10 and 114.05 cm during 2010-11 respectively). Janagoudar *et al.,* (2004) and Ninganur *et al.,* (2004) reported that drought tolerant genotypes recorded less reduction in plant height in cotton. Cotton hybrids JK Durga BG-I, Bunny BG-I and Bunny BG-II recorded significantly lower values for plant height compared to other hybrids at boll maturity stage in both the years of study.

Number of Sympodia Plant-1

Number of sympodia per plant as affected by water stress at harvesting stage among *Bt* cotton hybrids are presented in Table 1. Significant differences were observed between main treatments, cotton hybrids and their interactions. The mean number of sympodia per plant is significantly lower under rainfed condition compared to irrigated condition.

This might be due to water stress under rainfed condition. At harvest, cotton hybrids under rainfed condition recorded 31.64 and 32.92 percent reduction in mean number of sympodia per plant respectively compared to irrigated condition in both the years of study. Ghongane *et al.,* (2009) observed that plant height, number of monopodial and sympodial branches per plant and total dry matter produced were significantly reduced under water stress condition in *Bt* cotton.

Among the cotton hybrids tested, Tulasi 9 BG-II recorded highest mean number of sympodia per plant (23.08 and 22.67) followed by Tulasi 9 BG-I (22.08 and 22.17) and Bunny BG-I (19.83 and 21.50) respectively in both the years. JK Durga BG-I (8.32 and 10.67), Rasi Early BG-II (8.35 and 10.00) and Rasi Early BG-I (8.63 and 10.00) recorded lower mean number of sympodia per plant respectively in both the years.

Similar significant differences were detected among cotton varieties for length and number of sympodial and monopodial branches by Alishah and Ahmadikhah (2009). Among the interactions, under irrigated condition, significantly higher number of sympodia per plant was noticed in Tulasi 9 BG -II (26.70 and 26. 67) followed by Tulasi 9 BG-I (25.33 and 26.33) and Bunny BG- I (24.17 and 25.33) respectively in both the years of 2009-10 and 2010-11, where as Rasi Early BG-II (10.57 and 12.67), Rasi Early BG-I (10.90 and 12.33) and JK Durga BG-I (10.87 and 13.67) recorded lower number of sympodia per plant. Under rainfed condition, highest number of sympodia per plant was recorded in Tulasi 9 BG-II (19.47 and 18. 67) followed by Tulasi 9 BG-I (18.83 and 18.00) and Bunny BG- I (15.50 and 17.67) respectively in both the years. The entries JK Durga BG-I (5.77 and 7.67), Rasi Early BG-II (6.13 and 7.33) and Rasi Early BG-I (6.37 and 7.67) recorded lower number of sympodia per plant. Ratnakumari and Subbaramamma (2006) also reported that genetic variation was found among cotton genotypes for growth, yield, drought parameters and fibre quality and evaluated Gshv 97 / 612 had highest mean performance for number of sympodia per plant.

Days to 50% Flowering

The data on days taken to complete 50% flowering among the twelve *Bt* cotton hybrids as affected by soil moisture treatments (irrigated and rainfed) are presented in Table 2. Significant differences were observed between main treatments during first year of trial (2009-10) and cotton hybrids during both years, however interaction was not significant. The mean days to 50% flowering was significantly lowered by 13.49% under rainfed condition compared to irrigated condition. This may be due to induced synchronised flowering due to moisture stress. These findings are in confirmity with the report of Patil *et al.,* (2004), who reported that cotton genotypes showed early squaring, flowering, boll opening and maturity under rainfed conditions. The plants under water stress had higher blooming rates, early in the growing season than plants in the irrigated conditions. Early flowering had been observed under water stress.

Irrigated plants maintain their vegetative growth longer after the initiation of reproductive growth than the plants under water stress conditions (Pettigrew, 2004a). Among the cotton hybrids tested, Rasi Early BG-I took lesser number of days to 50% flowering (59.67) followed by Rasi Early BG-II (61.33) and JK Durga BG-I (62.67), where as RCH2 BG-II took more number of days to 50% flowering (66.67) followed by Tulasi 9 BG-I (65.33) and Tulasi 9 BG-II (65.17) during 2009-10. During 2010-11, among the hybrids tested, Rasi Early BG-I took lesser number of days to 50% flowering (61.83) followed by Rasi Early BG-II (62.50), Kisan Early BG-II(62.67) and JK Durga BG-I (63.50), where as RCH2 BG-II took more number of days to 50% flowering (70.67) followed by RCH 138 BG-I (68.00), RCH2 BG-I (66.50) and Tulasi 9 BG-I (65.50). Similar results were reported by Pettigrew (2004 a) in cotton. Alishah and Ahmadikhah (2009) reported that significant differences were detected among cotton varieties for days to 50% flowering under stress and non-stress conditions.

Table 1: Effect of water stress on plant height (cm) and number of sympodia per plant at harvest in *Bt* cotton hybrids

Name of the entry/genotype	2009-10			2010-11			2009-10			2010-11		
	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean
Bunny BG-I	114.50	98.40	106.45	101.87	87.83	94.85	24.17	15.50	19.83	25.33	17.67	21.50
Bunny BG-II	111.80	95.80	103.80	99.83	85.87	92.85	19.53	13.43	16.48	20.33	14.00	17.17
Kisan Early BG - I	110.87	93.63	102.25	98.40	82.47	90.43	18.87	13.93	16.40	19.67	14.33	17.00
Kisan Early BG – II	113.73	96.60	105.17	103.63	87.70	95.67	18.00	13.87	15.93	19.33	13.33	16.33
RCH 2 BG- I	135.80	115.40	125.60	125.40	107.50	116.45	12.70	7.70	10.20	16.33	10.67	13.50
RCH 2 BG- II	127.77	108.80	118.28	122.47	104.50	113.48	12.97	7.97	10.47	16.67	10.33	13.50
Rasi Early BG-I	135.83	114.83	125.33	123.73	103.77	113.75	10.90	6.37	8.63	12.33	7.67	10.00
Rasi Early BG-II	134.70	114.90	124.80	124.33	103.97	114.15	10.57	6.13	8.35	12.67	7.33	10.00
Tulasi 9 BG-I	126.93	108.07	117.50	120.47	106.50	113.48	25.33	18.83	22.08	26.33	18.00	22.17
Tulasi 9 BG-II	130.27	112.20	121.23	121.03	107.07	114.05	26.70	19.47	23.08	26.67	18.67	22.67
JK Durga BG-I	101.50	82.10	91.80	95.20	79.23	87.22	10.87	5.77	8.32	13.67	7.67	10.67
RCH 138 BG-I	125.00	102.43	113.72	114.07	97.00	105.53	19.53	14.67	17.10	20.67	14.67	17.67
Mean	**122.39**	**103.60**	--	**112.54**	**96.12**	--	**17.51**	**11.97**	-	**19.17**	**12.86**	-

	2009-10			2010-11			2009-10			2010-11		
	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction
SEm±	0.79	1.72	0.81	1.00	1.01	0.62	0.16	0.40	0.32	0.15	0.53	0.32
CD at 0.05	4.80	5.06	NS	6.10	2.98	1.83	0.97	1.19	0.94	0.93	1.57	0.93
CV (%)	4.19	3.74	1.68	5.76	3.18	1.77	6.46	6.74	5.33	5.75	8.17	4.41

Days to 50% Boll Bursting

The data on days taken to 50% boll opening among the *Bt* cotton hybrids as affected by moisture stress are presented in Table 2. The crop exposed to moisture stress at post flowering growth during both the years of experimentation. There were significant differences between main treatments, cotton hybrids and their interactions with regards to days to 50% boll opening. The mean days to 50% boll opening was significantly lower under rainfed condition (102.42 during 2009-10 and 105.25 during 2010-11) compared to irrigated condition (118.31 during 2009-10 and 120.17 during 2010-11). This might be due to early cessation of plant life cycle due to end of season moisture stress. Similar findings were reported by Patil *et al.,* (2004), who observed that cotton genotypes showed early flowering, squaring, boll opening and maturity under rainfed condition. In the present study, cotton hybrids under rainfed condition attained early boll opening by about 15.89 and 14.92 days in both the years respectively compared to irrigated condition. Moisture stress consistently affects reproductive growth in cotton. Plants under water stress had higher blooming rates, early in the growing season than plants in the irrigated condition. Early flowering had been observed under water stress. Hence plant comes to boll bursting quickly under rainfed condition. Irrigated plants maintain their vegetative growth longer after the initiation of reproductive growth than the plants under water stress condition (Pettigrew, 2004 a).

Among the cotton hybrids tested, Rasi Early BG-II took less number of days to 50% boll opening (104.83) followed by Rasi Early BG-I(107.00) and JK Durga BG-I (108.67), where as RCH2 BG-I took more number of days to 50% boll opening (114.33) followed by RCH2 BG-II(112.67) and Bunny BG-I and BG-II(112.50) during 2009-10. However, during 2010-11, Rasi Early BG-I took less number of days to 50% boll opening (108.17) followed by Rasi Early BG-II (108.83) and JK Durga BG-I (111.17), where as RCH2 BG-I took more number of days to 50% boll opening (117.00) followed by Bunny BG-I(114.83), Kisan Early BG-II (114.50) and Bunny BG-II (113.83). Alishah and Ahmadikhah (2009) reported that significant differences were detected among cotton varieties for days to 50% flowering and days to 50% boll bursting under stress and non-stress condition. Similar results are reported by Pettigrew (2004 a) in *Bt* cotton hybrids. During 2010-11, among the interactions, under irrigated conditions Rasi Early BG-I and BG-II took less number of days to 50% boll opening (114.33 and 116.67 respectively), whereas RCH2 BG-I and BG-II and Bunny BG-I took more number of days to 50% boll opening (124.67, 124.33 and 122.33 respectively). Under rainfed conditions Rasi Early BG-I and RCH2 BG-II took less number of days to 50% boll opening (99.67 and 101.67 respectively), where as Kisan Early BG-II, RCH2 BG-I and RCH 138 BG-I took more number of days (110.00,109.33 and 108.00 respectively) to 50% boll opening.

Physiological Parameters

Leaf Area per Plant (cm2palnt -1)

The leaf area per plant as affected by moisture stress at peak flowering and boll development stages among *Bt* cotton hybrids are furnished in Table 3. Production and maintenance of leaf area is important for dry matter production and yield.

The leaf area per plant showed a gradual increase from peak flowering to boll development stage and then declined in all the cotton hybrids at boll maturity stage in both the years of study. Significant differences were observed between main treatments and cotton hybrids with regards to leaf area per plant in both the years.

The interaction between main treatments and cotton hybrids was significant at peak flowering and boll development stage during 2010-11 only. Similar significant differences were observed in cotton by Pace *et al.,* (1999).

The mean leaf area values of cotton hybrids were significantly lower under rainfed condition compared to irrigated condition. This might be due to the reduction of whole plant leaf area largely through reduction in total leaf number and also due to the reduced leaf expansion which in turn reduced the size of individual leaf (Gibb *et al.,* 1990). Reduced leaf area in stressed plants was also observed by Berlin *et al.,* (1982). A reduction in cell growth is one of the earliest effects of water deficit. This, in turn, results in small leaves on stressed plants.

Table 2: Effect of water stress on days to 50 per cent flowering and 50 per cent boll opening of *Bt* cotton hybrids

Name of the entry/genotype	2009-10			2010-11			2009-10			2010-11		
	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean
Bunny BG-I	68.67	60.33	64.50	64.67	62.37	63.52	120.33	104.67	112.50	122.33	107.33	114.83
Bunny BG-II	69.33	60.67	65.00	65.33	64.33	64.83	119.33	105.67	112.50	121.33	106.33	113.83
Kisan Early BG - I	68.33	59.33	63.83	64.33	63.33	63.83	118.33	102.67	110.50	120.33	104.33	112.33
Kisan Early BG – II	67.67	57.67	62.67	63.67	61.67	62.67	117.00	100.33	108.67	119.00	110.00	114.50
RCH 2 BG- I	69.67	59.67	64.67	67.67	65.33	66.50	122.67	106.00	114.33	124.67	109.33	117.00
RCH 2 BG- II	71.67	61.67	66.67	69.67	71.67	70.67	121.67	103.67	112.67	124.33	101.67	113.00
Rasi Early BG-I	64.67	54.67	59.67	62.00	61.67	61.83	114.67	99.33	107.00	116.67	99.67	108.17
Rasi Early BG-II	66.33	56.33	61.33	62.33	62.67	62.50	112.33	97.33	104.83	114.33	103.33	108.83
Tulasi 9 BG-I	69.33	61.33	65.33	65.33	65.67	65.50	118.33	103.00	110.67	119.33	105.33	112.33
Tulasi 9 BG-II	68.67	61.67	65.17	64.67	64.33	64.50	117.67	103.33	110.50	118.67	104.00	111.33
JK Durga BG-I	67.67	57.67	62.67	63.67	63.33	63.50	117.00	100.33	108.67	118.67	103.67	111.17
RCH 138 BG-I	70.33	60.33	65.33	68.67	67.33	68.00	120.33	102.67	111.50	122.33	108.00	115.17
Mean	**68.53**	**59.28**	--	**65.17**	**64.47**	--	**118.31**	**102.42**	--	**120.17**	**105.25**	--

	2009-10			2010-11			2009-10			2010-11		
	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction
SEm±	0.53	0.53	0.30	0.40	1.03	0.46	1.01	1.04	0.50	1.01	1.19	0.82
CD at 0.05	3.25	1.55	NS	NS	3.02	NS	6.12	3.04	NS	6.13	3.48	2.42
CV (%)	5.02	2.03	2.26	4.23	4.19	2.19	5.47	2.30	2.38	5.36	2.58	1.90

Cotton hybrids grown under rainfed condition recorded 25.64 and 25.62% reduction in leaf area at peak flowering and 25.39 and 25.06% reduction at boll development stage respectively in both the years compared to irrigated condition. Similar reduction in leaf area by about 40-85% was observed in plants grown under dry land conditions in cotton (Burke *et al.,* 1985). Pettigrew (2004) reported that drought stress reduced over all plant stature with a 35% leaf area index reduction and prompting an 8% reduction in solar radiation interception. The reduced leaf area in stressed plants resulted primarily from a mitotic sensitivity to water stress (Berlin *et al.,* 1982). Among the cotton hybrids tested at peak flowering stage, Tulasi 9 BG-II recorded highest leaf area per plant (6531.87cm2 and 6128.93 cm2) in both the years respectively followed by Bunny BG-II(6400.07cm2) during 2009-10; Tulasi 9 BG-I (5898.53 cm2) during 2010-11; Tulasi 9 BG-I (6310.16cm2) during 2009-10; Bunny BG-II(5878.85 cm2) during 2010-11 and Bunny BG-I (6325.06 cm2 and 5855.46 cm2) in both the years respectively, whereas lowest leaf area per plant was recorded by RCH2 BG-I (4643.26 cm2) followed by Rasi Early BG-I (4665.42 cm2), BG-II (4855.92 cm2) and JK Durga BG-I (5014.77 cm2) during 2009-10; and during 2010-11 Rasi Early BG-I recorded lowest leaf area per plant (4505.09 cm2) which was significantly on a par with RCH2BG-I(4560.86cm2), JK Durga BG-I (4566.80 cm2) and Rasi Early BG-II (4620.70 cm2). The same trend was observed in leaf area per plant at boll development stage in both the years. Tulasi 9 BG-I, BG-II, Bunny BG-I and BG-II recorded significantly higher leaf area per plant compared to other hybrids at both the stages, where as Rasi Early BG-I, BG-II and JK Durga BG-I recorded significantly lower leaf area at both the stages. Among the interactions, the cotton hybrids Tulasi 9 BG-II, BG-I and Bunny BG-I recorded higher leaf area per plant both under irrigated as well as rainfed conditions, where as Rasi Early BG-I and BG-II recorded lesser leaf area per plant both under irrigated as well as rainfed conditions. The genotypes with higher leaf area under rainfed conditions produced higher biomass, there by higher yields and maintaining higher leaf area is also a desirable trait under moisture stress condition (Ratnakumari *et al.,* 2004). Ninganur *et al.,* (2004) reported less reduction in plant height, plant spread and leaf area by drought tolerant cotton genotypes. Hence Tulasi 9 BG-II,BG-I and Bunny BG-I maintained higher leaf area and so maintained total dry matter under rainfed conditions probably due to higher photosynthesizing area.

Total Drymatter (g/plant-1)

The data on total dry matter of *Bt* cotton hybrids as affected by moisture stress at peak flowering (75 DAS), boll development (105 DAS) and boll maturity stages (135 DAS) are presented in tables 4 and 5. Dry matter accumulation and distribution is an important factor indicating partitioning efficiency of a genotype. In general, soil moisture determines the accumulation of dry matter in different plant parts. The data indicated that the total dry matter production increased from squaring stage to boll maturity stage in all the cotton hybrids in both the years. There was significant difference between main treatments and genotypes with regards to total dry matter in both the years. The interaction between main treatments and genotypes was significant at peak flowering, boll development and boll maturity stages in both the years. Similar significant differences were observed in *Bt* cotton hybrids by Ghongane *et al.,* (2009).

The mean total dry matter values of cotton hybrids were significantly lower under rainfed condition compared to irrigated condition. Cotton hybrids grown under rainfed condition recorded 23.01 and 8.74% reduction at peak flowering stage; 27.70 and 24.37% reduction at boll development stage and 28.41 and 28.90% reduction at boll maturity stage compared to irrigated condition in both the years respectively. Variability in percent reduction of dry matter was observed in accordance with stress levels during crop period. As the water stress increased, the total dry matter decreased in cotton (Chun-Yan-Wang *et al.,* 2007). Ghongane *et al.,* (2009) reported that plant height, number of monopodial branches plant-1, sympodial branches plant-1 and total dry matter (g plant-1) significantly reduced under no irrigation condition in *Bt* cotton compared to irrigated condition. Plants grown under dry land conditions exhibited 40-85% decrease in leaf number, leaf area index, plant height and total dry matter in cotton (Burke *et al.,* 1985). Water stress at any stage of growth adversely affected both vegetative growth and major metabolic processes like photosynthesis, stomatal conductance which ultimately results in reduction of biomass production.

Table 3: Effect of water stress on leaf area (cm^2 $plant^{-1}$) at peak flowering (75 DAS) and boll development stage (105 DAS) of *Bt* cotton hybrids

Name of the entry/genotype	2009-10			2010-11			2009-10			2010-11		
	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean
Bunny BG-I	7090.37	5559.75	6325.06	6468.07	5242.85	5855.46	9633.97	7711.86	8672.91	8198.79	6691.88	7445.33
Bunny BG-II	7378.30	5421.84	6400.07	6645.25	5112.44	5878.85	9058.65	7043.59	8051.12	8428.66	6571.95	7500.30
Kisan Early BG - I	6483.40	4949.35	5716.38	5853.89	4271.81	5062.85	7594.30	5638.10	6616.20	7455.02	5482.84	6468.93
Kisan Early BG–II	6618.41	4897.05	5757.73	5760.29	4164.51	4962.40	9607.91	7478.39	8543.15	7762.13	5591.93	6677.03
RCH 2 BG- I	5555.10	3731.43	4643.26	5336.47	3785.24	4560.86	7963.87	4953.94	6458.90	6836.94	4986.10	5911.52
RCH 2 BG- II	6154.87	4288.99	5221.93	5617.43	3930.92	4774.18	7809.21	5594.11	6701.66	7086.68	5104.43	6095.56
Rasi Early BG-I	5586.46	3744.37	4665.42	5388.59	3621.59	4505.09	7375.39	5066.09	6220.74	6796.06	4677.25	5736.65
Rasi Early BG-II	5636.55	4075.28	4855.92	5524.30	3717.10	4620.70	7357.54	5172.38	6264.96	6726.63	4518.33	5622.48
Tulasi 9 BG-I	7018.89	5601.43	6310.16	6492.84	5304.22	5898.53	9079.89	7143.89	8111.89	8226.63	6710.00	7468.31
Tulasi 9 BG-II	7144.41	5919.32	6531.87	6751.15	5506.71	6128.93	9362.07	7638.86	8500.46	8409.89	6881.47	7645.68
JK Durga BG-I	5917.05	4112.48	5014.77	5445.20	3688.39	4566.80	7358.57	5100.21	6229.39	6984.93	4827.53	5906.23
RCH 138 BG-I	6826.22	5251.73	6038.97	6511.51	5057.13	5784.32	8761.90	6782.13	7772.01	8182.73	6223.06	7202.89
Mean	**6450.83**	**4796.08**	--	**5982.92**	**4450.24**	--	**8413.61**	**6276.96**	--	**7591.26**	**5688.90**	--

	2009-10			2010-11			2009-10			2010-11		
	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction
SEm±	71.88	146.72	74.35	44.81	120.05	65.92	66.65	221.69	111.94	57.14	133.27	75.98
CD at 0.05	437.41	430.33	NS	272.67	352.11	193.36	405.58	650.25	NS	347.75	390.90	222.87
CV (%)	7.67	6.39	5.65	5.15	5.64	2.86	5.44	7.39	4.87	5.16	4.92	2.71

In addition, water stress affects both the production and distribution of carbohydrates, and thus partitioning of carbohydrates between sources and sinks (Pettigrew, 2004).

Among the cotton hybrids tested at boll maturity stage, Tulasi 9 BG-II recorded highest mean total dry matter (396.89 g/plant and 367.60 g/plant) and it was on a par with other cotton hybrids viz., Tulasi 9 BG-I(386.73 g/plant and 364.82 g/plant) and Bunny BG-I(391.33g/plant and 360.23g/plant) in both the years respectively, where as JK Durga BG-I recorded lowest mean total dry matter (225.51 g/plant and 205.67 g/plant) and it was on a par with other cotton hybrids Rasi Early BG-II (233.65 g/plant and 211.88 g/plant) and Rasi Early BG-I(234.09 g/plant and 212.71g/plant) in both the years respectively. The same trend was observed in total dry matter production at peak flowering and boll development stages in both the years. Genetic variation was present in cotton genotypes for dry matter, yield and drought characters (Ratnakumari and Subbaramamma, 2006). Drought tolerant cotton genotypes showed more total dry matter production (Janagoudar *et al.*, 2004 and Ninganur *et al.*, 2004).

Among the interactions, at boll maturity stage, under irrigated conditions Tulasi 9 BG-II recorded highest total dry matter followed by Bunny BG-I, whereas under rainfed conditions, Tulasi 9 BG-II recorded highest total dry matter followed by Bunny BG-I and Tulasi 9 BG-I in both the years. On the other hand, JK durga BG-I recorded lowest total dry matter followed by Rasi Early BG-II under irrigated conditions, whereas under rainfed conditions JK Durga BG-I recorded minimum total dry matter followed by Rasi Early BG-II and Rasi Early BG-I. In the present study, the high biomass hybrids Tulasi 9 BG-II, Tulasi 9 BG-I and Bunny BG-I also maintained higher photosynthesizing area (leaf area) during crop growth period, irrespective of treatments. Wright and Rao (1992) reported that cultivars with vigorous early growth, a relatively large biomass accumulation and capacity for remobilizing stored assimilates to reproductive sinks may be better adapted to drought stress. Hence it is evident that these three hybrids Tulasi 9 BG-II, Tulasi 9 BG-I and Bunny BG-I maintained higher seed cotton yield under stress conditions also.

Seed Cotton Yield (kg ha-1)

The data on seed cotton yield of Bt cotton hybrids as affected by soil moisture stress at harvest are furnished in table 5. Significant differences were observed between main treatments, genotypes and their interaction with regards to seed cotton yield in both the years. The mean seed cotton yield was significantly lower under rainfed condition compared to irrigated condition. This might be due to water stress occurred in rainfed condition. At harvest, cotton hybrids under rainfed condition recorded 39.32 and 25.62% reduction in mean seed cotton yield compared to irrigated condition in both the years respectively. According to Karademir *et al.*, (2011), seed cotton yield decreased by 48.04% and fiber yield decreased by 49.41% due to water stress in cotton genotypes. Water stress is the most important factor limiting crop productivity and adversely affects fruit production, square and boll shedding, lint yield and fiber quality properties in cotton (El-Zik and Thaxton, 1989). Cotton yield is dependent on boll number and their size. In adequate resource availability such as soil water deficit, during early development of reproductive organs greatly limits the growth capacity of individual bolls (Stewart, 1986).

Among the cotton hybrids tested, Tulasi 9 BG-II recorded highest mean seed cotton yield (3320.21 and 3236.16 kg ha -1) followed by Tulasi 9 BG –I (3113.20 and 3145.08 kg ha -1) and Bunny BG-I (3095.63 and 3018.45 kg ha -1),where as JK Durga BG-I recorded lowest mean seed cotton yield (`1348.50 and 1333.06 kg ha-1) followed by Rasi Early BG-II (1388.86 and 1406.65 kg ha-1) and Rasi Early BG-I (1430.81 and 1441.84 kg ha -1) in both the years respectively. Among the interactions, Tulasi 9 BG-II, Tulasi 9 BG-I and Bunny BG-I produced higher seed cotton yield under rainfed (stress) conditions, while Tulasi 9 BG-II produced highest seed cotton yield under irrigated conditions (non-stress) also. Karademir *et al.*, (2011) reported that there was significant difference observed among cotton genotypes and water stress treatments for seed cotton yield and quality parameters, and stated that SER 18 and Stoneville-468 cotton genotypes produced higher yield under water stress conditions while Stoneville-468 produced higher yield under well irrigated conditions also. The present findings are in accordance with Karademir *et al.*, (2011) in cotton. More tolerant plants generally show a greater accumulation of dry mass and/or yield under water deficits than under other environmental conditions (Kumar *et al.*, 2008).

Table 4: Effect of water stress on total dry matter (g plant^{-1}) at peak flowering (75 DAS) and boll development stage (105 DAS) of *Bt* cotton hybrids

Name of the entry/genotype	2009-10			2010-11			2009-10			2010-11		
	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean
Bunny BG-I	198.06	163.02	180.54	164.70	159.57	162.13	398.03	310.53	354.28	329.34	272.04	300.69
Bunny BG-II	186.18	148.66	167.42	164.40	159.18	161.79	361.93	287.65	324.79	321.40	259.58	290.49
Kisan Early BG - I	163.41	123.06	143.24	146.57	132.58	139.58	280.73	202.89	241.81	255.13	193.64	224.38
Kisan Early BG – II	168.03	127.07	147.55	147.23	134.98	141.11	298.89	213.21	256.05	256.88	195.40	226.14
RCH 2 BG- I	153.34	115.26	134.30	133.03	116.18	124.60	269.22	179.95	224.59	233.02	166.42	199.72
RCH 2 BG- II	157.52	114.54	136.03	132.74	113.45	123.10	278.97	194.18	236.58	234.88	163.26	199.07
Rasi Early BG-I	141.44	102.73	122.09	119.01	97.77	108.39	252.47	167.30	209.89	219.62	141.07	180.35
Rasi Early BG-II	142.44	100.40	121.42	118.29	98.00	108.14	249.33	166.86	208.09	219.72	142.89	181.31
Tulasi 9 BG-I	193.98	164.67	179.33	172.16	168.52	170.34	394.05	308.16	351.10	339.54	275.84	307.69
Tulasi 9 BG-II	201.11	166.56	183.84	174.60	169.42	172.01	403.71	314.05	358.88	342.79	285.90	314.34
JK Durga BG-I	141.10	99.62	120.36	115.56	95.58	105.57	248.69	160.91	204.80	218.15	138.03	178.09
RCH 138 BG-I	168.90	126.07	147.48	154.06	144.74	149.40	338.16	222.83	280.50	297.15	236.98	267.06
Mean	**167.96**	**129.31**	**--**	**145.20**	**132.50**	**--**	**314.52**	**227.38**	**--**	**272.30**	**205.92**	**--**

	2009-10			2010-11			2009-10			2010-11		
	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction
SEm±	1.58	1.93	1.14	1.66	1.94	1.60	2.68	3.32	2.44	2.23	2.27	1.93
CD at 0.05	9.65	5.65	3.35	10.11	5.70	4.69	16.34	9.74	7.17	13.60	6.66	5.67
CV (%)	6.40	3.17	2.11	7.18	3.43	2.05	5.95	3.00	2.95	5.61	2.33	2.34

Table 5: Effect of water stress on total dry matter (g plant^{-1}) at boll maturity stage (135 DAS) and seed cotton yield of *Bt* cotton hybrids

Name of the entry/genotype	2009-10			2010-11			2009-10			2010-11		
	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean	Irrigated	Rainfed	Mean
Bunny BG-I	439.02	343.64	391.33	402.16	318.31	360.23	3770.58	2420.69	3095.63	3343.91	2693.00	3018.45
Bunny BG-II	413.04	320.38	366.71	381.61	292.11	336.86	3448.62	2404.07	2926.34	3211.79	2589.25	2900.52
Kisan Early BG - I	311.71	222.87	267.29	306.30	207.85	257.07	2246.92	1413.99	1830.45	2157.51	1589.83	1873.67
Kisan Early BG – II	329.26	231.37	280.32	298.48	208.95	253.72	2197.61	1359.57	1778.59	2053.54	1600.42	1826.98
RCH 2 BG- I	304.75	199.96	252.35	288.21	188.35	238.28	2195.66	1202.96	1699.31	2067.10	1375.81	1721.46
RCH 2 BG- II	313.22	215.07	264.15	281.58	185.39	233.49	2058.25	1195.81	1627.03	1858.14	1462.16	1660.15
Rasi Early BG-I	283.72	184.45	234.09	262.16	163.27	212.71	1857.98	1003.65	1430.81	1695.98	1187.71	1441.84
Rasi Early BG-II	282.72	184.57	233.65	260.81	162.95	211.88	1832.17	945.55	1388.86	1685.73	1127.56	1406.65
Tulasi 9 BG-I	431.94	341.53	386.73	410.40	319.24	364.82	3696.55	2529.84	3113.20	3499.15	2791.00	3145.08
Tulasi 9 BG-II	445.61	348.16	396.89	411.63	323.56	367.60	3992.43	2647.98	3320.21	3577.98	2894.33	3236.16
JK Durga BG-I	273.78	177.25	225.51	257.69	153.64	205.67	1811.98	885.01	1348.50	1588.46	1077.67	1333.06
RCH 138 BG-I	383.82	246.34	315.08	370.54	271.74	321.14	3213.54	1604.17	2408.85	3093.91	1799.36	2446.64
Mean	**351.05**	**251.30**	**--**	**327.63**	**232.95**	**--**	**2693.52**	**1634.44**	**-**	**2486.10**	**1849.01**	**-**

	2009-10			2010-11			2009-10			2010-11		
	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction	Main plots	Genotypes	Interaction
SEm ±	2.72	5.33	3.37	2.26	3.47	1.79	31.09	128.73	73.90	33.57	115.37	66.40
CD at 0.05	16.54	15.63	9.88	16.20	10.18	5.25	189.20	377.57	228.77	204.32	338.38	201.76
CV (%)	5.41	4.33	2.64	5.70	3.04	1.42	8.62	14.57	6.77	9.29	13.04	8.52

Conclusion

Bt cotton hybrids showed reduction in terms of morphological, physiological parameters and seed cotton yield under rainfed condition in both the years of study. In terms of genotypic performance under moisture stress (rainfed) condition, the *Bt* cotton hybrids Tulasi 9 BG-II, Tulasi 9 BG-I and Bunny BG-I recorded higher number of sympodia per plant, leaf area and total dry matter in addition to higher seed cotton yield in both the years.

It is evident from the present study that these three cotton hybrids Tulasi 9 BG-II, Tulasi 9 BG-I and Bunny BG-I are not only drought tolerant but also are high yielders. The Bt cotton hybrids Jk Durga BG-I, Rasi Early BG-I and Rasi Early Bg-II showed poor performance in terms of growth and yield parameters.

ACKNOWLEDGEMENT

I am highly thankful to my guides Dr.Y.Ashoka Rani and Dr.S.Ratnakumari for their constant help and guidance throughout my research work.

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