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Abscission of Fruiting Structures in *Bt* and non-*Bt* Cotton in Relation to Abiotic Factors and Agronomic Intervention under Rainfed Condition

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ABSTRACT

Keywords

Abscission of fruiting structures, Abiotic factors, Bt and non-Bt cotton, NPK levels, Spacing

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A two year field experiment was conducted to elucidate relation of abscission of fruiting structures in cotton (*Gossypium hirsutum*) with abiotic factors and effect of agronomic intervention viz., spacing (90 × 60 cm and 90 × 45 cm) and NPK levels (50:25:25, 62.5:31.25:31.25 and 75:37.5:37.5 kg NPK ha^{-1}) on abscission of fruiting structures, leaf reddening and chlorophyll content in Bt and non-Bt cotton of same genotype, following split plot design with 4 replicates at Akola. Abscission of fruiting structures increased linearly with increase in morning relative humidity and number of rainy days in a week. However, relations with minimum temperature, evening relative humidity and rainfall were non linear and varied according to their range. Minimum temperature range of 20-22 °C, evening relative humidity beyond 52% and rainfall more than 60 mm in a week were most critical for abscission. Bt cotton lost more fruiting structures through abscission, recorded maximum leaf reddening, but gave higher seed cotton yield. Whereas, non-Bt recorded maximum chlorophyll content. Spacing of 90 x 45 cm compensated abscission losses and recorded higher seed cotton yield than 90 x 60 cm. Application of 75:37.5:37.5 kg NPK ha^{-1} recorded higher seed cotton yield by minimizing abscission and leaf reddening with improvement in chlorophyll content but was at par with 62.5:31.25:31.25 kg NPK ha-1. Thus, it can be conclude that to harness higher seed cotton yield under rainfed condition Bt cotton should be sown at 90 x 45 cm spacing and fertilized with 62.5:31.25:31.25 kg NPK ha^{-1}.

Introduction

In India, cotton is cultivated on 11.87 million ha with a production of 5.74 million tons of seed cotton and productivity 484 kg ha^{-1}. Though, the productivity has been doubled with the adoption of Bt cotton hybrids as compared to pre Bt cotton era (191 kg ha^{-1}) but still it is considerably lower than the major cotton growing countries like Brazil (1533 kg ha^{-1}), China (1489 kg ha^{-1}), USA (859 kg ha^{-1}) and Pakistan (528 kg ha^{-1}). At present bollworm complex is not a limiting factor for realizing yield targets in genetically modified hybrids of cotton. But retention of early formed squares and its successful conversion into bolls is a prime challenge; particularly in rainfed cotton which shares 64.10 percent of total cotton growing area in India. Abiotic factors, plant nutrition, agronomic intervention and genotype itself influence the retention of fruiting structures through its effect on growth and physiology of cotton plant. In cotton, shedding of fruiting structures may be up to 65-70 percent in the form of squares, flowers and small bolls (Baloch *et al.,* 2000). Goswami and Dayal (1998) opined that the physiological disturbance contributes 7-35 and 42-64 percent abscission of unopened flowers and bolls, respectively. Although, abscission of squares and young bolls is a natural phenomenon and cotton plant can recover yield. But it is decisive in determining yield per unit area under rainfed situation where soil moisture is a limiting factor in later stages for formation of new fruiting positions and if corrected would increase the yield considerably.

Similarly, leaf reddening has become a major physiological disorder in Bt cotton, causes 15-25 percent yield loss depending on severity (Raju and Thakare, 2012). Reddening in Bt cotton might be associated with changes in their morphological, phenological and physiological characteristics (Chen *et al.*, 2002). Since a host factors related to the transformation process and the background genotype contribute to the altered transgenic expression and agronomic performance (Showalter *et al.,* 2009). Leaf reddening influence the photosynthetic efficiency and photosynthetic area of cotton; thus, directly governs the number of fruiting positions and its retention.

Crop management practices that increase the retention of early formed fruiting structures in cotton can produce higher yield even in short growing season. The management of abiotic factors like weather parameters that promotes abscission of fruiting structures is beyond the reach of farmers. As a consequence, the present study was conducted to observe pertinent influence of these abiotic factors on abscission of fruiting structures in cotton and sort out exact nature and degree of relationship that exists between them for devising comprehensive management strategy to harness more yield.

Materials and Methods

Experimental site

A field experiment was carried out at Cotton Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, India during rainy seasons of 2008-09 and 2009-10. The experimental site was situated at 307.4 meter above the mean sea level at 22° 42’ N latitude and 77° 02’ E longitude and having subtropical continental climate. Study site characterized by a hot summer and general dryness throughout the year except during South-West monsoon. About 75 percent of rainfall received during June to 15th September. The site receives an annual mean precipitation of 805.6 mm in about 46 rainy days and grouped under assured rainfall zone. July is the wettest month with 253.1 mm average monthly rainfall. The mean maximum temperature varies from 29.0 °C during winter to about 42.7 °C in May; whereas, mean minimum temperature varies from 10.3 °C during winter to 27.6 °C in summer. Mean maximum temperature during the course of experimentation ranged between 27.8 to 34.6 °C and mean minimum temperature ranged between 9.4 to 26.1 °C during 2008-09, while corresponding values for a subsequent year were 27.2 to 35.2 °C and 10.2 to 24.9 °C, respectively. The experimental soil was clayey, low in organic carbon (0.40%), slightly alkaline in reaction (pH 8.15), low in available nitrogen (150.53 kg ha^{-1}) and available phosphorus (15.97 kg ha^{-1}) and fairly high in available potassium (394.50 kg ha^{-1}).

Treatments and experimental design

The experiment comprises total twelve treatment combinations of two cotton hybrids (*Gossypium hirsutum*) *viz*., Bt and non-Bt of same genotype NCS 145, two spacings *viz*., 90 × 60 cm (recommended for non-Bt) and 90 × 45 cm and three NPK levels *viz*., 50:25:25 kg NPK ha^{-1} (recommended for non-Bt), 62.5:31.25:31.25 kg NPK ha^{-1} and 75:37.5:37.5 kg NPK ha^{-1} were studied in split plot design with four replications. The treatment combinations of cotton hybrids (V) and spacings (S) were allotted to main plots, whereas, NPK levels (F) were taken in subplots. Half of the N and full dose of P and K were applied as basal application at the time of sowing and remaining half dose of N was top-dressed at 30 days after sowing as per treatments. The experimental field was kept free from weeds during critical weed competition period. Similarly, plant protection measures were undertaken as and when the population incidence of particular pest reached to ETL in particular treatment.

Abscission of fruiting structures

Total number of naturally abscised fruiting structures (squares, flowers and green bolls) on five observational plants were counted at weekly interval, starting from 41 days after sowing to 194 days after sowing and expressed as a percentage of sum of total number of intact fruiting structures on plant, number of fruiting structures dropped due to bollworm damage and number of naturally abscised fruiting structures and mean was obtained. To express data in tabular form consecutive two weeks abscission percentage were summed up. However, over a season abscission percentage was calculated by expressing the total number of naturally abscised fruiting structures during a season as a percentage of total number of fruiting position on plant.

Impact of abiotic factors

To find out the impact of abiotic factors on abscission of fruiting structures in cotton, the data on weather parameters such as weekly maximum and minimum temperature, morning and evening relative humidity, rainfall and BSH were collected from meteorological observatory of the university during the period of experimentation and correlated with weekly percent abscission of fruiting structures.

Estimation of total chlorophyll content (mg g^{-1})

For uniformity in sampling, 3rd leaf from the top of cotton plant was utilized for chlorophyll estimation. Extraction was done in DMSO (Dimethyl sulfoxide) according to Hiscox and Israelstam (1979). Leaf sample weighing 50 mg was put into 10 ml of the extractant and was held for 2 hours at 60 ^{0}C. The supernatant was used for estimation of chlorophyll. Absorbance was recorded at 652 nm on Autospectrophotometer. The amount of total chlorophyll was calculated using Arnon's (1949) formula.

Total chlorophyll (mg g^{-1}) =

$$\frac{(\text{O.D. at 652 nm}) \times 1000}{34.5} \times \frac{V}{1000 \times W}$$

Where, V = Final volume of DMSO (ml), W = Fresh weight of sample (g) and O.D. = Optical density

Leaf reddening (%)

Percent leaf reddening was calculated by expressing number of red leaves (bronz leaves) on five observational plants as a percentage of sum of total number of functional (green) leaves and red leaves on plant.

Data analysis

The analysis of data was carried out as per method described by Gomez and Gomez (1984). The statistical analysis of the percent abscission of fruiting structures and abiotic factors was made by using correlation and regression package and after regression it was equated.

Results and Discussion

Abscission of fruiting structures (%)

Effect of abiotic factors

The percent abscission of fruiting structures showed negative correlation with maximum temperature, BSH and evaporation during 2008-09. However, during 2009-10 the corresponding relation was observed with evening relative humidity, rainfall and rainy days. Whereas, for rest of the weather parameters in respective years it possesses a positive correlation (Table 1).

The negative relationship between abscission of fruiting structures and BSH during 2008-09 was factuality, as during this year because of cloudy weather during peak period of fruiting (37 and 38 MW) BSH was the main limiting factor for square and flower setting. Prolonged cloudy weather with high temperature induces use of stored photosynthates in old leaves, which otherwise would be utilized for retention and development of young fruiting structures. Guinn (1986) also opined that prolonged cloudy weather causes excessive shedding of flowers and buds. While during 2009-10 negative correlation between abscission of fruiting structures and rainfall was the result of dry spell during peak period of fruiting (37, 38 and 39 MW); which became a critical factor for square and flower setting. As self-regulating phenomenon, cotton plant adjusts the boll load in accordance with moisture availability. In this concerned Guinn and Brummett (1987) reported that water deficit stress in cotton increases the proportion of ABA than IAA; which, increase secretion of cellulose enzyme responsible for weakening of cells in abscission zone by degrading cell wall and thus leads to shedding of fruiting structures. Furthermore, moisture stress significantly increased fruit shedding by diminishing assimilate supply towards young fruiting structures as it lowered the rate of photosynthesis by increasing stomatal resistance to entry of CO_2 (Pettigrew, 2004). Negative effect of moisture stress on square and boll setting were also observed by Aujla *et al.,* (2005) and Loka (2012).

Among all the weather parameters minimum temperature, morning relative humidity, evening relative humidity, rainfall and rainy days had significantly positive influence on abscission of fruiting structures during 2008-09. Thus to know the exact nature of relationship between them; a forth degree polynomial relationship was calculated and depicted in Figure 1. The abscission of fruiting structures decrease gradually with increase in minimum temperature from 9 to 12 °C (Fig. 1a). Whereas, rise in minimum temperature beyond 12 °C resulted steep increase in abscission and was at its maximum magnitude when minimum temperature ranged between 20 to 22 °C. Thereafter, decrease in abscission with increase in minimum temperature up to 24 °C was observed. Singh *et al.,* (2007) reported that night temperature exclusively affect square shedding either by suppressing the development of reproductive meristem or by increased abortion of young squares. Echer *et* *al.*, (2014) observed that increasing night temperature during flower bud formation stage increased its rate of production but at the same time rate of abortion also increased. In this connection Loka and Oosterhuis (2016) found that high night temperature immediately increase the leaf respiration rate and membrane damage and markedly decrease leaf photosynthesis and ATP levels which resulted in disruption of flower bud carbohydrate metabolism and abscission.

As regard relative humidity, abscission of fruiting structures increased steadily with increase in morning relative humidity from 58 to 80%. Whereas, increase beyond 80% resulted steep increase in abscission up to 94% of morning relative humidity (Fig. 1b). Increase in evening relative humidity from 16 to 28% gradually increased abscission (Fig. 1c). Whereas between 28 to 52% of evening relative humidity, it became more or less constant. However, abscission increased with an increasing rate when evening relative humidity increased from 52 to 71%. This effect of relative humidity on abscission of fruiting structures might be associated with cloudy weather and low BSH; as higher relative humidity prevails during such weather condition.

The abscission of fruiting structures gave interesting response to amount of rainfall received in a particular week. The receipt of small amount of rainfall up to 22 mm per week gradually increased shedding. Whereas, increase in rainfall amount from 22 to 58 mm per week decreased the same. However, increase in rainfall amount more than 60 mm in a particular week steeply increased the abscission of fruiting structures (Fig. 1d). Increase in number of rainy days in particular meteorological week gradually increased the abscission of fruiting structures (Fig. 1e). Continuous wet period resulted in anaerobic condition in clayey soils, this distorted cotton root respiration and plant metabolism. Similarly, low soil oxygen causes closing of stomata; that leads to reduction in photosynthesis and evaporative cooling which increases shedding of fruiting structures. Further, ethylene induced abscission of young fruiting structures might have contributed to it as anaerobic condition in soil leads to production of ethylene in plant roots.

The plant physiological processes are governed by different weather parameters and their intricacies; thus, it is quite unfair to blame single weather parameter for abscission. Hence, to obtained a clear view in this regard multiple regression equation was fitted for 2008-09 data by taking abscission of fruiting structures (Y) as a dependent variable and weather parameters (X) as independent variables. This equation explained the amount of changes in percent abscission of fruiting structures per unit changes in weather parameter, indicated that there was significant contribution of abiotic factors (83%) for variation in abscission of fruiting structures.

$$Y = 17.84 - 1.08\ X_1 - 0.05\ X_2 + 0.07\ X_3 + 0.08\ X_4 - 0.14\ X_5 + 2.28\ X_6 + 0.89\ X_7 - 0.46\ X_8 + 1.30\ X_9$$

Where, Y = Percent abscission of fruiting structures, X_1 = Maximum temperature (°C), X_2 = Minimum temperature (°C), X_3 = Morning relative humidity (%), X_4 = Evening relative humidity (%), X_5 = Rainfall (mm), X_6 = No. of rainy days, X_7 = BSH (hr/day), X_8 = Wind speed (km hrs^{-1}) and X_9 = Evaporation (mm).

Effect of agronomic interventions

Data on percent abscission of fruiting structures as influenced periodically by different treatments are presented in Table 2 and 3 for the years 2008-09 and 2009-10, respectively. Perusal of data indicates that during 2008-09, average loss of fruiting structures due to abscission was higher (13.90%) between 69-82 days after sowing (DAS). Thereafter 8.14 percent loss was occurred between 139-152 DAS and this was more prominent in non-Bt cotton (14.96 %); that was due to occurrence of subsequent flush of squares on non-Bt cotton because of damage of early formed fruiting bodies by bollworms. Similarly during 2009-10 peak period of fruiting i.e., 55-82 DAS was found to be most susceptible period for loss of fruiting structures, resulted 22.24 to 25.88 percent abscission of fruiting structures. During both the years peak period of squaring and boll formation was most susceptible for natural abscission of fruiting structures. In this regard Crozat *et al.,* (1999) opined that week after appearance of squares and post anthesis in flowers are most vulnerable period for abscission of fruiting structures in cotton. As it is incapable to supply photosynthate to all fruiting structures, while cell wall thickening in a peduncle of developing bolls prevents the formation of abscission layer in later stages.

Among cotton hybrids Bt cotton exhibited significantly more shedding of fruiting structures between 41-54, 69-82, 97-110 and 111-124 DAS than non-Bt cotton hybrid during 2008-09 (Table 2). On the contrary between 55-68 DAS and from 125 days onwards to 194 DAS, the corresponding result was obtained with non-Bt. However, between 83-96 DAS the result was not significant. Similarly, during 2009-10 (Table 3) at initial stage i.e., between 41-110 DAS and between 125-138, 153-166 DAS Bt cotton recorded significantly more shedding fruiting structures than non-Bt. Whereas, between 111-124 and 139-152 DAS, non-Bt cotton exhibited significantly more shedding than Bt. Result was not significant between 167-180 and 181-194 DAS. The data of over season abscission (Table 2 and 3) revealed 28.85 and 54.48 percent loss of fruiting structures due to abscission during 2008-09 and 2009-10, respectively. The difference between Bt and non-Bt cotton hybrids was not significant during 2008-09. However, during 2009-10 Bt cotton hybrid recorded significantly more abscission of fruiting structures (62.59%) throughout the season than non-Bt. Significantly maximum shedding of fruiting structures in Bt cotton at initial stage might be the result of malnutrition of newly formed fruiting bodies because of more fruiting load at initial stage in Bt cotton than non-Bt. Whereas, in non-Bt cotton considerable numbers of newly formed fruiting bodies damaged by a bollworm which might have lowered the competition within retained developing squares and bolls on the individual plant.

Spacing did the significant influence on abscission of fruiting structures between 83-96, 125-138 DAS during 2008-09 and between 69-82, 111-124, 125-138, 153-166 and 167-180 DAS during 2009-10. The spacing of 90 x 60 cm recorded significantly minimum abscission than 90 x 45 cm at above stages during both the years. Similarly, in over season abscission spacing of 90 x 60 cm was promising for significantly minimizing the loss of fruiting structures than 90 x 45 cm during 2009-10. Whereas, during 2008-09 result was non significant. The significant reduction in abscission of fruiting structures could be because of less competition for soil moisture and nutrients at lower plant density due to less number of plants per unit area than higher plant density. Further amount of solar radiation harvested by plant canopy also have considerable effect on shedding of fruiting structures. In high plant density cotton tend to grow tall to harness more solar radiation but covered the leaf below with deep shade and utilized the prepared photosynthate for vertical growth again. Due to this phenomenon cotton fails to fulfill the photosynthate requirement of developing fruiting bodies, this result in abscission of young squares and bolls. The significant increase in shedding of fruiting structures with increase in plant density was also reported by Abd El-Aal (2014).

NPK levels significantly influenced percent abscission of fruiting structures at all the stages of observations during both the years, except between 139-152 DAS during both the years and between 153-166, 181-194 DAS during 2008-09. Application of 75:37.5:37.5 kg NPK ha^{-1} resulted significant reduction in abscission of fruiting structures at all the stages of observation during both the years and found to be at par with 62.5:31.25:31.25 kg NPK ha^{-1} at 69-82, 83-96, 97-110, 111-124, 167-180 DAS during 2008-09 and 41-54, 55-68, 69-82, 83-96, 97-110, 125-138, 153-166 DAS during 2009-10. In case of over season abscission, application of 75:37.5:37.5 kg NPK ha^{-1} and 62.5:31.25:31.25 kg NPK ha^{-1} were comparable with each other and recorded significantly minimum abscission percentage over 50:25:25 kg NPK ha^{-1} during both the years. Application of 75:37.5:37.5 kg NPK ha^{-1} resulted 24.17 and 14.21 percent reduction in fruit abscission over 50:25:25 kg NPK ha^{-1} during 2008-09 and 2009-10, respectively. Significant reduction in shedding of fruiting structures at higher level of NPK attributed to increase in total chlorophyll content in this treatment. Similarly, increasing nutrient supply might have increased the NPK reserved in leaves and stem. The extreme weather conditions like long dry spell (Wang *et al.,* 2014), anaerobic soil condition for long period due to heavy rainfall (Dodd *et al.,* 2013) and deviation of temperature from optimum temperature requirement of cotton (Shakoor *et al.,* 2017) adversely affects the nutrient uptake by cotton roots. Thus, under such conditions the nutrients reserve in plant acted as buffer to cope with malnutrition of newly formed and developing fruiting bodies. The present results corroborate the findings of Dar and Khan, (2004), Bismillah and Shbbir (2006) and Elhamamsey *et al.,* (2016) they reported significant decrease in shedding with higher fertilizer level.

Leaf reddening (%)

A red or bronze leaf is one of the physiological disorder impair photosynthetic efficiency and consequently yield in cotton. The Figure 2 illustrates that leaf reddening percent increased precipitously with the advancement of the crop towards maturity. Pujar *et al.,* (2018) also observed that reddening typically occurred 112 days after sowing when plant bears heavy boll load and extend with age of cotton crop. Among the cotton hybrids, Bt cotton showed significantly higher reddening percent than non-Bt cotton (Fig. 2a). This result supported the findings of Hosmath *et al.,* (2012). The significant increase in reddening percentage in Bt cotton might be the result of nutrient stress experienced by Bt cotton plants due to more fruiting load at initial stage. In this concern Nagender *et al.,* (2017) noticed that Bt cotton hybrid has more requirement of nutrients particularly at boll development stage. Thus, it can be conclude that Bt cotton required application of incremental rate of nitrogen along with phosphorus and potassium to take care of reddening malady.

The spacing of 90 x 60 cm spacing resulted significantly minimum reddening percentage than 90 x 45 cm at 90 DAS whereas, at subsequent stages of observation result failed to attain the level of significance (Fig. 2b). Application of 75:37.5:37.5 kg NPK ha^{-1} was found to be most effective in reducing reddening in cotton (Fig. 2c), which significantly lowered leaf reddening percentage at all stages of observations than lower levels of NPK. This might be because of availability of ample amount of NPK to cotton plants during peak boll development stage. Which otherwise result in nutrient sorption from leaves and stem for want of reproductive development and thus, resulted in degradation of chlorophyll in leaves and formation of anthocyanin. These results are supported by the findings of Hosamani *et al.*, (2018), they reported that increased in N application along with P and K increased the supply of N to leaf and reduced the formation of anthocyanin at the cost of chlorophyll. It reveals the significance of crop nutrition in management of leaf reddening malady in cotton.

Total chlorophyll content (mg g^{-1})

The total chlorophyll content increased from 0.801 mg g^{-1} at 30 DAS to 1.432 mg g^{-1} at 120 DAS and decrease subsequently to 1.100 mg g^{-1} at 150 DAS (Table 4). The non-Bt cotton recorded significantly higher total chlorophyll content than Bt cotton at 120 and 150 DAS. Although, the result was non significant at initial stages non-Bt cotton recorded maximum chlorophyll content than Bt cotton. Masram *et al.*, (2015) also reported significantly higher total chlorophyll content in non-Bt cotton than Bt. The spacing of 90 x 60 cm resulted significantly maximum total chlorophyll content at 120 DAS. Whereas, at rest of the stages result was non significant. Lower value of total chlorophyll content under higher plant density might be resultant of competition for nutrients. Similar result was also reported by Jahedi *et al.*, (2013). Application of 75:37.5:37.5 kg NPK ha^{-1} significantly increased total chlorophyll content at all the stages of growth over lower levels of NPK but was at par with 62.5:31.25:31.25 kg NPK ha^{-1} at 60 and 150 DAS. The increase in total chlorophyll content with the increase in NPK levels is indicative of fact that nutrients play a vital role in chlorophyll formation and consequently photosynthesis. Santhosh *et al.*, (2015) also observed increase in chlorophyll content with increase in NPK level in cotton.

Seed cotton yield (kg ha^{-1})

Despite considerable loss of fruiting structures in abscission, Bt cotton hybrid significantly contributed to seed cotton yield over non-Bt (Table 5). This attributed to resistance of Bt cotton to bollworms and thus, more number of picked bolls per plant.

Table.1 Correlation between percent abscission of fruiting structures in cotton and weather parameters

Weather parameters	Correlation coefficient (r)	
	2008-09	2009-10
Maximum temperature (°C)	-0.2931	0.0392
Minimum temperature (°C)	0.4262*	0.1526
Morning relative humidity (%)	0.6148**	0.0764
Evening relative humidity (%)	0.5812**	-0.0066
Rainfall (mm)	0.5153*	-0.1008
No. of rainy days	0.6542**	-0.1492
BSH (hrs)	-0.0376	0.2027
Wind speed (km hrs^{-1})	0.3007	0.2408
Evaporation (mm)	-0.4106	0.0677

*Significant at 0.05 level (r = 0.413) (n = 22)
** Significant at 0.01 level (r = 0.526)

Table.2 Abscission of fruiting structures (%) in Bt and non Bt cotton as influenced by spacing and NPK levels at various crop growth stages and over a season (2008-09)

Treatments	Days after sowing											Over a season abscission
	41-54	**55-68**	**69-82**	**83-96**	**97-110**	**111-124**	**125-138**	**139-152**	**153-166**	**167-180**	**181-194**	
Meteorological week	**33, 34**	**35, 36**	**37, 38**	**39, 40**	**41, 42**	**43, 44**	**45, 46**	**47, 48**	**49, 50**	**51, 52**	**01, 02**	
Cotton hybrids												
V_1 Bt Cotton	2.06^{a} (1.43)*	3.71^{b} (1.90)*	16.39^{a} (3.94)	6.76^{a} (2.50)*	3.11^{a} (1.54)*	2.04^{a} (1.42)*	1.03^{b} (0.95)*	1.32^{b} (1.11)*	0.54^{b} (0.62)*	0.26^{b} (0.46)*	0.28^{b} (0.42)*	**29.99^{a} (32.94)****
V_2 Non-Bt Cotton	1.43^{b} (1.16)	6.05^{a} (2.36)	11.42^{b} (3.33)	6.54^{a} (2.43)	2.67^{b} (1.34)	1.67^{b} (1.25)	2.73^{a} (1.62)	14.96^{a} (3.87)	1.12^{a} (0.95)	1.62^{a} (1.21)	1.32^{a} (0.96)	**27.71^{a} (31.65)**
LSD (*p* = 0.05)	0.17	0.25	0.39	NS	0.19	0.16	0.16	0.24	0.13	0.17	0.09	**NS**
Spacing (cm)												
S_1 90 x 60	1.71^{a} (1.29)	5.04^{a} (2.13)	13.48^{a} (3.57)	6.10^{b} (2.33)	2.73^{a} (1.38)	1.68^{a} (1.27)	1.62^{b} (1.19)	7.45^{a} (2.38)	0.74^{a} (0.77)	0.80^{a} (0.76)	0.74^{a} (0.66)	**27.91^{a} (31.71)**
S_2 90 x 45	1.78^{a} (1.30)	4.72^{a} (2.13)	14.33^{a} (3.70)	7.19^{a} (2.60)	3.05^{a} (1.50)	2.03^{a} (1.40)	2.14^{a} (1.39)	8.82^{a} (2.59)	0.91^{a} (0.81)	1.09^{a} (0.91)	0.86^{a} (0.72)	**29.79^{a} (32.88)**
LSD (*p* = 0.05)	NS	NS	NS	0.26	NS	NS	0.16	NS	NS	NS	NS	**NS**
NPK levels (kg ha^{-1})												
F_1 50:25:25	2.31^{a} (1.51)	6.15^{a} (2.42)	16.59^{a} (3.99)	8.34^{a} (2.79)	4.07^{a} (1.85)	2.23^{a} (1.49)	2.15^{a} (1.40)	8.85^{a} (2.59)	0.85^{a} (0.80)	1.21^{a} (0.95)	0.98^{a} (0.73)	**33.63^{a} (35.34)**
F_2 62.5:31.25:31.25	1.63^{b} (1.29)	4.82^{a} (2.14)	13.14^{b} (3.53)	6.01^{b} (2.28)	2.44^{b} (1.32)	1.74^{b} (1.29)	1.91^{a} (1.31)	8.09^{a} (2.49)	0.90^{a} (0.81)	0.87^{b} (0.80)	0.72^{a} (0.69)	**27.43^{b} (31.32)**
F_3 75:37.5:37.5	1.30^{c} (1.09)	3.67^{b} (1.83)	11.99^{b} (3.39)	5.60^{b} (2.32)	2.15^{b} (1.15)	1.59^{b} (1.23)	1.58^{b} (1.15)	7.48^{a} (2.38)	0.73^{a} (0.75)	0.75^{b} (0.77)	0.69^{a} (0.65)	**25.50^{b} (30.22)**
LSD (*p* = 0.05)	0.18	0.28	0.37	0.29	0.19	0.15	0.13	NS	NS	0.14	NS	**3.59**
Mean	**1.75 (1.29)**	**4.88 (2.13)**	**13.90 (3.64)**	**6.65 (2.46)**	**2.89 (1.44)**	**1.85 (1.33)**	**1.88 (1.29)**	**8.14 (2.49)**	**0.83 (0.79)**	**0.94 (0.84)**	**0.80 (0.69)**	**28.85 (32.29)**

() Square root values, ()* √x+0.05 values, ()** Angular transformed values

[a] The same letter indicates no significant difference

Table.3 Abscission of fruiting structures (%) in Bt and non Bt cotton as influenced by spacing and NPK levels at various crop growth stages and over a season (2009-10)

Treatments	**Days after sowing**											**Over a season abscission**
	41-54	**55-68**	**69-82**	**83-96**	**97-110**	**111-124**	**125-138**	**139-152**	**153-166**	**167-180**	**181-194**	
Meteorological week	**34, 35**	**36, 37**	**38, 39**	**40, 41**	**42, 43**	**44, 45**	**46, 47**	**48,49**	**50, 51**	**52, 01**	**02, 03**	
Cotton hybrids												
V_1 Bt Cotton	3.00^{a} (1.66)*	29.46^{a} (5.42)	24.40^{a} (4.89)	12.35^{a} (3.44)	2.51^{a} (1.55)*	1.54^{b} (1.15)*	12.73^{a} (3.55)	0.48^{b} (0.60)*	6.15^{a} (2.46)	12.41^{a} (3.51)	16.46^{a} (3.96)	**62.59^{a}**
V_2 Non-Bt Cotton	1.32^{b} (1.12)	22.31^{b} (4.72)	20.08^{b} (4.45)	8.53^{b} (2.86)	1.23^{b} (0.94)	3.49^{a} (1.83)	11.02^{b} (3.30)	0.74^{a} (0.80)	3.81^{b} (1.94)	13.33^{a} (3.63)	16.06^{a} (3.98)	**46.37^{b}**
LSD (*p* = 0.05)	0.21	0.27	0.35	0.34	0.18	0.18	0.24	0.09	0.18	NS	NS	**3.04**
Spacing (cm)												
S_1 90 x 60	1.87^{a} (1.34)	24.95^{a} (4.99)	20.28^{b} (4.46)	9.81^{a} (3.03)	1.64^{a} (1.18)	2.12^{b} (1.35)	10.89^{b} (3.28)	0.55^{a} (0.68)	4.47^{b} (2.09)	12.08^{b} (3.45)	15.69^{a} (3.89)	**52.89^{b}**
S_2 90 x 45	2.45^{a} (1.44)	26.82^{a} (5.15)	24.20^{a} (4.88)	11.06^{a} (3.27)	2.10^{a} (1.31)	2.91^{a} (1.63)	12.86^{a} (3.57)	0.68^{a} (0.72)	5.50^{a} (2.31)	13.65^{a} (3.68)	16.83^{a} (4.06)	**56.06^{a}**
LSD (*p* = 0.05)	NS	NS	0.35	NS	NS	0.18	0.24	NS	0.18	0.21	NS	**3.04**
NPK levels (kg ha^{-1})												
F_1 50:25:25	3.21^{a} (1.68)	28.22^{a} (5.31)	26.73^{a} (5.14)	13.00^{a} (3.50)	2.70^{a} (1.54)	2.98^{a} (1.65)	13.89^{a} (3.72)	0.64^{a} (0.71)	5.81^{a} (2.38)	15.03^{a} (3.87)	18.85^{a} (4.31)	**59.02^{a}**
F_2 62.5:31.25:31.25	1.70^{b} (1.30)	25.26^{b} (5.01)	20.45^{b} (4.48)	9.68^{b} (3.07)	1.56^{b} (1.13)	2.53^{a} (1.50)	11.53^{b} (3.38)	0.68^{a} (0.72)	4.80^{b} (2.16)	12.62^{b} (3.54)	16.29^{a} (4.01)	**53.79^{b}**
F_3 75:37.5:37.5	1.57^{b} (1.18)	24.17^{b} (4.89)	19.53^{b} (4.40)	8.63^{b} (2.87)	1.35^{b} (1.06)	2.04^{b} (1.31)	10.21^{b} (3.18)	0.52^{a} (0.66)	4.34^{b} (2.06)	10.95^{c} (3.29)	13.65^{b} (3.59)	**50.63^{b}**
LSD (*p* = 0.05)	0.20	0.29	0.36	0.35	0.13	0.18	0.24	NS	0.15	0.22	0.37	**3.23**
Mean	**2.16 (1.39)**	**25.88 (5.07)**	**22.24 (4.67)**	**10.44 (3.15)**	**1.87 (1.25)**	**2.52 (1.49)**	**11.88 (3.43)**	**0.61 (0.70)**	**4.98 (2.20)**	**12.87 (3.57)**	**16.26 (3.97)**	**54.48**

() Square root values, ()* √x+0.05 values,

[a] The same letter indicates no significant difference

Table.4 Total chlorophyll content (mg g^{-1}) of Bt and non Bt cotton as influenced by spacing and NPK levels (pooled of two years)

Treatments	Days after sowing				
	30	60	90	120	150
Cotton hybrids					
V_1 Bt Cotton	0.797^a	0.868^a	1.365^a	1.392^b	**1.040^b**
V_2 Non-Bt Cotton	0.806^a	0.874^a	1.396^a	1.472^a	**1.160^a**
LSD (p = 0.05)	NS	NS	NS	0.071	**0.088**
Spacing (cm)					
S_1 90 x 60	0.794^a	0.901^a	1.408^a	1.477^a	**1.120^a**
S_2 90 x 45	0.808^a	0.841^a	1.354^a	1.387^b	**1.080^a**
LSD (p = 0.05)	NS	NS	NS	0.071	**NS**
NPK levels (kg ha^{-1})					
F_1 50:25:25	0.759^b	0.814^b	1.317^b	1.373^b	**1.058^b**
F_2 62.5:31.25:31.25	0.797^b	0.883^a	1.375^b	1.422^b	**1.088^{ab}**
F_3 75:37.5:37.5	0.848^a	0.916^a	1.451^a	1.501^a	**1.155^a**
LSD (p = 0.05)	0.048	0.045	0.064	0.068	**0.071**
Mean	**0.801**	**0.871**	**1.381**	**1.432**	**1.100**

[a] The same letter indicates no significant difference

Table.5 Seed cotton yield (kg ha^{-1}) of Bt and non Bt cotton as influenced by spacing and NPK levels (pooled of two years)

Treatments	Seed cotton yield (kg ha^{-1})
Cotton hybrids	
V_1 Bt Cotton	1019.68a
V_2 Non-Bt Cotton	900.39b
LSD (p = 0.05)	42.22
Spacing (cm)	
S_1 90 × 60	902.05b
S_2 90 × 45	1018.03a
LSD (p = 0.05)	42.22
NPK levels (kg ha^{-1})	
F_1 50:25:25	918.63b
F_2 62.5:31.25:31.25	976.96a
F_3 75:37.5:37.5	984.52a
LSD (p = 0.05)	41.33

[a] The same letter indicates no significant difference

Fig.1 Relation of abscission of fruiting structures with minimum temperature (1a), morning relative humidity (1b), evening relative humidity (1c), rainfall per week (1d) and number of rainy days per week (1e) during 2008-09

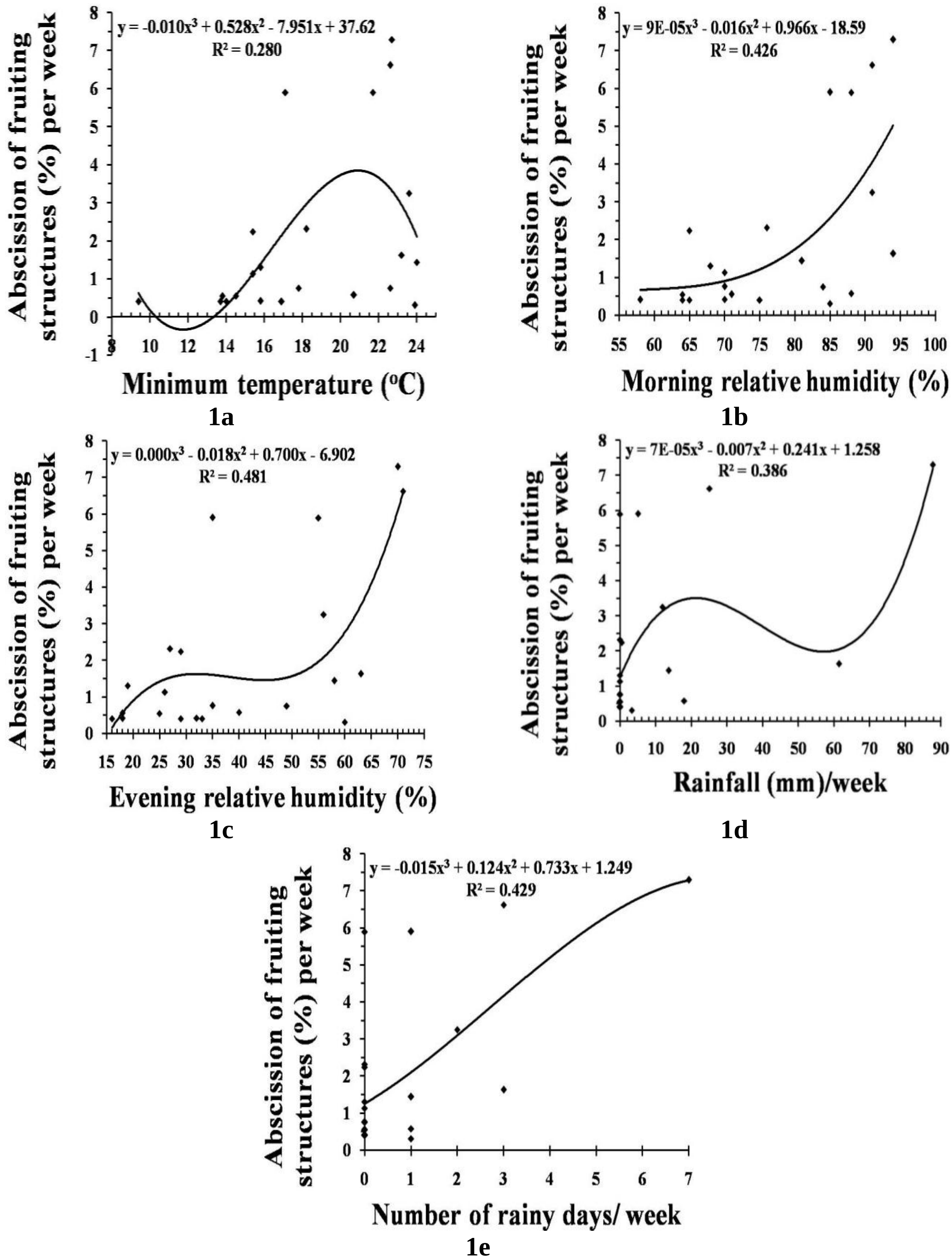
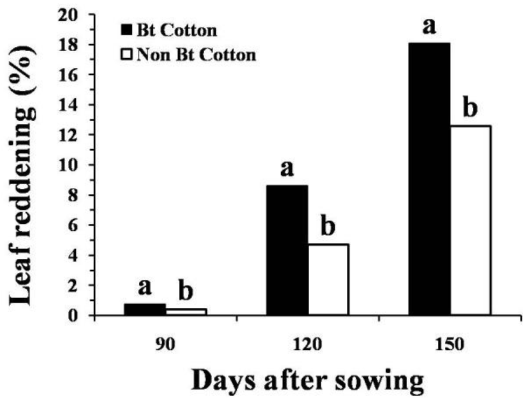
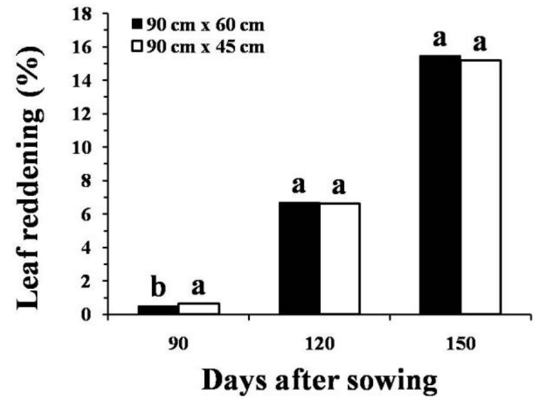


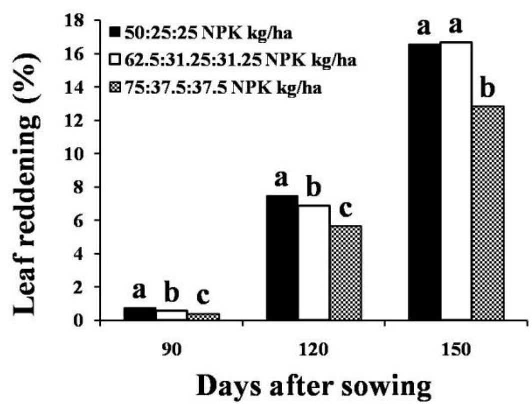
Fig.2 Leaf reddening as influenced by Bt and non-Bt cotton, spacing and NPK levels at different crop growth stages (pooled of two years). The same letter indicates no significant difference (p = 0.05)



2a



2b



2c

Similarly, early retention of bolls in Bt cotton because of low bollworm damage might have got the advantage of available soil moisture and nutrient during boll development stage which in turn reflected in higher seed cotton yield. Buttar and Singh (2006) and Patil *et al.*, (2009) reported higher seed cotton yield in Bt cotton hybrids than non-Bt. The spacing of 90 x 45 cm recorded significantly higher seed cotton yield over 90 x 60 cm. This result indicates that higher plant density in cotton compensate the yield loss due to abscission of fruiting structures under rainfed condition. As unavailability of sufficient soil moisture due to early withdrawal of monsoon limits the vegetative and reproductive growth in later stage and thus, consequently formation of new fruiting positions under rainfed situation. Similar result was also reported by Reddy and Kumar (2010). The increase in NPK levels increased the seed cotton yield; however, difference between 75:37.5:37.5 and 62.5:31.25:31.25 kg NPK ha^{-1} was non significant. Hence, application of 62.5:31.25:31.25 kg NPK ha^{-1} was found to be optimum for realization of maximum seed cotton yield under rainfed condition. The significant increase in seed cotton yield with higher levels of NPK over 50:25:25 kg NPK ha^{-1} found to be associated with lower leaf reddening percentage, increase in total chlorophyll content and retention of more number of bolls per plant due to significant reduction in shedding of fruiting structures. These results are in conformity with the findings of Bhalerao and Gaikwad (2010).

On the basis of experimental results, it can be concluded that the period with low BSH, high night temperature particularly in the range of 20 to 22 °C, morning relative humidity above 80% and evening relative humidity above 52%, weekly rainfall more than 60 mm with more numbers of rainy days induced abscission of fruiting structures in cotton. Bt cotton give higher seed cotton yield by recompensing the loss of fruiting structure in abscission with retention of early formed fruiting bodies. Similarly, higher plant density performed better under rainfed condition by compensating the effect of abiotic factors on fruit abscission. Application of 75:37.5:37.5 kg NPK ha^{-1} minimizes abscission of fruiting structures and leaf reddening in cotton by increase in leaf chlorophyll content; however, application of 62.5:31.25:31.25 kg NPK ha^{-1} has been optimum for achieving higher seed cotton yield under rainfed condition.

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