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Impact of agronomic intervention and abiotic factors on bollworm infestation in BT and non-Bt cotton (*Gossypium hirsutum* L.) under rainfed condition

MR Thakur, BA Gudade and VM Bhale

Abstract

This experiment elucidates effect of agronomic intervention *viz.*, spacing and fertilizer levels and abiotic factors on bollworms infestation in Bt and non-Bt cotton. The investigation was carried out during 2008-09 and 2009-10 at Cotton Research Unit, Akola, Maharashtra, India. The experiment comprises two cotton hybrids *viz.*, Bt and non-Bt of same genotype NCS 145, two spacings *viz.*, 90 × 60 cm and 90 × 45 cm and three NPK levels *viz.*, 50:25:25 kg NPK ha^{-1}, 62.5:31.25:31.25 kg NPK ha^{-1} and 75:37.5:37.5 kg NPK ha^{-1}. The experiment was laid out in split plot design with four replications. The results revealed that the Bt cotton hybrid suppressed bollworm and loculi damage in fruiting bodies and recorded higher seed cotton yield than non-Bt. Cotton sown at closer spacing of 90 × 45 cm was more susceptible to bollworm infestation but recorded higher seed cotton yield over 90 × 60 cm. Bollworm infestation, loculi damage and seed cotton yield showed linear response to fertilizer levels. The percent bollworm infestation in non-Bt cotton exhibited positively significant relationship with abiotic factors *viz.*, minimum temperature, morning and evening relative humidity and rainfall. Whereas maximum temperature and BSH had non-significant positive and negative relation, respectively.

Keywords: Abiotic factors, bollworm infestation, Bt and non-Bt cotton, fertilizer, spacing

Introduction

Cotton is the most important natural fibre has been in the cultivation commercially for domestic consumption and export needs in about 111 countries worldwide and hence called "King of fibres" or "White gold". In India, cotton is cultivated on 11.88 million ha with a production of 5.98 million tonnes of seed cotton. The cotton production remained stagnant over the years due to many biotic and abiotic constraints. Among the biotic factors, insect pests are major constrain in India. The insect pests range of cotton is quite intricate and as many as 1326 species of insect pests have been found on cotton throughout the world. About 130 different species of insects and mites found to demolish cotton at different stages of crop growth in India [1]. Among these, bollworms *viz*., *Helicoverpa armigera* (Hubner), *Earias vittella* (Fabricius), *Earias insulana* (Boisdual) and *Pectinophora gossypiella* (Saunders) create greater threat to cotton production [2]. Transgenic Bt cotton expressing Cry1 A (b) and Cry1 A (c) insecticidal proteins have shown significant protection against major cotton bollworm pests like *Helicoverpa. aemigera* [3], *Earias vittela* [4], and *Pectinopora gossypiella* [5] in many countries of the world. But the agronomic performance of Bt cotton cultivars may vary substantially from their non-Bt counterparts [6]. When a transgene is introgressed into an elite genetic background, the agronomic performance may be altered as all the donor DNA from the originally transformed line is not eliminated through back-crossing. Additionally, a host factors related to the transformation process and the background genotype may contribute to the altered transgenic expression and agronomic performance [7]. Hence it was felt necessary to amend the agronomic practices of Bt cotton and study the effect of these agronomic intervention in respect of bollworm infestation against non-Bt counterpart of same genotype.

Among the abiotic factors, weather parameters viz., temperature, relative humidity, rainfall and bright sunshine hours (BSH) have great impact during crop season on the incidence, development and infestation of insect pest in crops. As a consequence, the present research was conducted to observe pertinent influence of these abiotic factors on bollworm infestation both in Bt and non-Bt cotton and sort out exact nature and degree of relationship that exists between them for devising comprehensive pest management strategy against bollworm.

2. Materials and Methods

2.1 Experimental site

The field experiment was carried out at Cotton Research Unit, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, India during the rainy seasons of 2008-09 and 2009-10. The experimental site was situated at 307.4 meters above the mean sea level at 22° 42’ N latitude and 77° 02’ E longitude and has subtropical continental climate. The soil of experimental plot was clayey in texture, low in organic carbon (0.40%), slightly alkaline in reaction (pH 8.15), low in available nitrogen (150.53 kg ha^{-1}) and phosphorus (15.97 kg ha^{-1}) and fairly high in available potassium (394.50 kg ha^{-1}).

2.2 Treatments and experiential design

Total twelve treatment combinations comprising two cotton hybrids 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. It was two years study, conducted on the same site with same randomization. The sowing was carried out on 3rd and 11th July during 1st and 2nd year, respectively. 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 weed free during critical weed competition period.

2.3 Percent bollworm infestation and loculi damage

Total number of green fruiting bodies (squares, flowers and green bolls) infested by bollworms (*Earias insulana* and *Helicoverpa armigera*) 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 bodies on plant, number of fruiting bodies dropped due to bollworm damage and number of naturally dropped fruiting bodies and mean was obtained. To express data in tabular form average of two weeks were obtained. However, over a season percent bollworm infestation was worked out by expressing total number of infested fruiting bodies during a season as a percentage of total number of fruiting position per plant. The number of locules infested with pink bollworms (*Pectinophora gossypiella*) on five observational plants in each net plot were counted at harvest and expressed as a percentage of total number of locules per plant and mean was obtained.

2.4 Impact of abiotic factors

In order to find out the impact of abiotic factors on the bollworm infestation 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 the weekly bollworm infestation.

2.5 Data analysis

The analysis of data was carried out as per method described by Gomez and Gomez (1984) [8]. The statistical analysis of the bollworm infestation and abiotic factors was made by using correlation and regression package and after regression it was equated.

3. Results and Discussion

3.1 Percent bollworms infestation in green fruiting bodies

Bt cotton hybrid exhibited resistance to *Helicoverpa armigera* and *Earias vittella* and recorded significantly minimum infestation in green fruiting bodies compared to its non-Bt counterpart at all the stages of observations (Table 1). Similarly, over season infestation was found significantly less in Bt cotton than non Bt. Moreover, it is interesting to note that Bt cotton never crossed economic threshold limit (ETL), however non-Bt crossed ETL (5 percent damage in green fruiting bodies on cotton plant) five times between 41-54, 55-68, 69-82, 139-152 and 153-166 days after sowing (DAS). This indicates that, effect of Bt gene was much more convincing in terms of bollworm damage in Bt cotton hybrid, where bollworm damage was significantly minimum than non-Bt. This was due to Cry 1Ac protein (Bt toxin) in the plant system which cause midgut paralysis to bollworms. Similar effect of Bt cotton in suppression of bollworm damage in green fruiting bodies over non-Bt were reported by Prasad *et al.* (2005) [9] and Manjunatha *et al.* (2009) [10].

Table 1: Percent bollworm infestation in green fruiting bodies of Bt and non-Bt cotton as influenced by spacing and fertilizer levels at various crop growth stages and over a season (pooled data: 2008-09 and 2009-10)

Treatments	Days after sowing (DAS)											Over a season
	41-54	55-68	69-82	83-96	97-110	111-124	125-138	139-152	153-166	167-180	181-194	
Cotton hybrids												
V_1 Bt Cotton	0.00 (0.22)*	0.00 (0.22)*	0.00 (0.22)*	0.00 (0.22)*	0.00 (0.22)*	0.00 (0.22)*	0.00 (0.22)*	0.15 (0.35)*	0.01 (0.23)*	0.00 (0.22)*	0.03 (0.25)*	0.19 (2.04)**
V_2 Non-Bt Cotton	5.56 (2.19)	7.49 (2.72)	10.55 (2.64)	1.40 (1.11)	1.26 (1.00)	4.30 (1.78)	0.81 (0.78)	6.68 (2.15)	5.62 (2.03)	0.64 (0.71)	0.68 (0.72)	24.73 (29.67)
LSD (p = 0.05)	0.11	0.11	0.12	0.06	0.04	0.06	0.06	0.10	0.08	0.10	0.05	0.94
Spacing (cm)												
S_1 90 × 60	2.64 (1.18)	3.46 (1.42)	4.65 (1.34)	0.65 (0.67)	0.43 (0.51)	2.00 (0.96)	0.32 (0.47)	2.87 (1.16)	2.37 (1.05)	0.23 (0.42)	0.28 (0.45)	11.36 (15.08)
S_2 90 × 45	2.92 (1.24)	4.03 (1.52)	5.90 (1.52)	0.75 (0.67)	0.83 (0.71)	2.30 (1.04)	0.49 (0.54)	3.96 (1.33)	3.26 (1.22)	0.41 (0.52)	0.42 (0.52)	13.55 (16.63)
LSD (p = 0.05)	NS	NS	0.12	NS	0.04	0.06	0.06	0.10	0.08	0.09	0.05	0.94
NPK levels (kg ha^{-1})												
F_1 50:25:25	2.78	3.56	4.85	0.62	0.55	2.02	0.31	3.19	2.66	0.27	0.27	11.22

	(1.18)	(1.43)	(1.34)	(0.62)	(0.56)	(0.96)	(0.44)	(1.22)	(1.07)	(0.44)	(0.43)	(15.30)
F_2 62.5:31.25:31.25	2.78 (1.22)	3.86 (1.50)	5.52 (1.46)	0.74 (0.68)	0.67 (0.61)	2.20 (1.01)	0.38 (0.50)	3.51 (1.26)	2.90 (1.16)	0.34 (0.47)	0.39 (0.49)	12.86 (15.97)
F_3 75:37.5:37.5	2.78 (1.23)	3.82 (1.49)	5.45 (1.49)	0.74 (0.70)	0.67 (0.66)	2.24 (1.03)	0.52 (0.58)	3.54 (1.27)	2.89 (1.17)	0.36 (0.50)	0.39 (0.53)	13.30 (16.30)
LSD (p = 0.05)	NS	NS	0.09	0.05	0.05	NS	0.05	NS	0.08	NS	0.03	NS

()* $\sqrt{x + 0.05}$ transformed values, ()** Angular transformed values, NS= Non-significant

The spacings under study exerted significant influence on percent bollworm infestation except, at 41-54, 55-68 and 83-96 DAS (Table 1). The closer spacing of 90 × 45 cm recorded significantly higher percent bollworm infestation over 90 × 60 cm. This might be due to favorable microclimate for growth, development and feeding of larva because of shedding effect under closed plant density. The present findings are in agreement with Singh *et al*. (2007), who reported that bollworm infestation was lower in wider spacing as compared to closer spacings [11]. Ilyas *et al*. (2010) also reported that infestation of bollworms was more severe on closely spaced cotton as against wider spaced [12].

The fertilizer levels did the significant influence on percent bollworm infestation in green fruiting bodies between 69-82, 83-96, 97-110, 125-138, 153-166 and 181-194 DAS (Table 1). Amongst three fertilizer levels, bollworm infestation was significantly lower with application of 50:25:25 kg NPK ha^{-1} over 62.5:31.25:31.25 and 75:37.5:37.5 kg NPK ha^{-1}. Notable differences were observed between application of 50:25:25 and 62.5:31.25:31.25 kg NPK ha^{-1}. However, effect of fertilizer levels on over a season infestation was non significant. In general, bollworm infestation increased with increasing level of fertilizer application. This indicates that differences in bollworm damage in green fruiting bodies recorded among the fertilizer levels, evidently affected by the amount of nutrient available to the plant and its accumulation in tissues. The cotton crop responds to different fertilizer levels by producing varying degree of growth and as a result, the micro climate of crop might become more congenial and plant may apparently more attractive to female moth of bollworm under higher doses of fertilizers. Therefore, application of 75:37.5:37.5 kg NPK ha^{-1} to cotton hybrids, more particular to non-Bt cotton hybrid (Table 3 - V × F interaction) might have attracted more number of bollworm moths for oviposition than lower fertilizer levels and thus resulted in more bollworm infestation.

Increasing rate of oviposition of *Helicoverpa armigera* with increase in nitrogen level in growth chamber was observed by Xia *et al*. (1997) [13] and under field condition by Ma *et al*. (2003) [14]. In this context, Muthukrishanan and Selvan (1993) [15] observed the significant linear relationship between the rate of feeding, assimilation and tissue production of insect and the fertilizer dosage and leaf nitrogen content in castor. Hence, from the foregoing discussion, it can be concluded that the growth of the cotton plant as influenced by levels of fertilizer has a definite bearing on the bollworms infestation in green fruiting bodies. The results of the present investigation are also supported by the findings of Pierce *et al*. (2001) [16], who reported that higher dose of nitrogenous fertilizer lead to excessive vegetative growth and crop succulence thereby attracting the bollworms resulting in increased damage in fruiting bodies of cotton.

The cotton hybrids showed significant influence on bollworm infestation at different spacing (Table 2). Bt cotton hybrid at both spacing i.e. 90 x 60 cm and 90 × 45 cm recorded significantly lower bollworm infestation compared to non-Bt cotton at respective spacing. Whereas, non-Bt cotton at 90 × 45 cm spacing was most susceptible to bollworm and recorded significantly maximum bollworm infestation as compared to rest of the combinations at different growth stages and in over season data. The results of the present study derive support from the findings of Anand *et al*. (2008), who also observed that non-Bt cotton hybrid was more susceptible to bollworm infestation at closer spacing (less than 90 × 60 cm) than Bt cotton hybrids [17].

A perusal of data in Table 3 indicates that cotton hybrids respond significantly in respect of bollworm infestation at different fertilizer level. The Bt cotton hybrid at all the three fertilizer levels recorded significantly lower bollworm infestation in green fruiting bodies as compared to non-Bt cotton. Whereas, in non-Bt cotton application of higher dose of fertilizer i.e. 75:37.5:37.5 kg NPK ha^{-1} was found most vulnerable to bollworm damage compared to lower levels at different growth stages and in over season data.

Table 2: Percent bollworm infestation in green fruiting bodies as influenced by cotton hybrid and spacing interaction (V × S) at different crop growth stages and over a season (pooled data: 2008-09 and 2009-10)

V / S	DAS								Over a season
	69-82	97-110	111-124	125-138	139-152	153-166	167-180	181-194	
V_1 S_1	0.00 (0.22*	0.00 (0.22*	0.00 (0.22*	0.00 (0.22*	0.16 (0.37*	0.02 (0.25*	0.00 (0.22*	0.06 (0.27*	0.12 (1.88)**
V_1 S_2	0.00 (0.22)	0.00 (0.22)	0.00 (0.22)	0.00 (0.22)	0.13 (0.34)	0.00 (0.22)	0.00 (0.22)	0.00 (0.22)	0.26 (2.20)
V_2 S_1	9.30 (2.46)	0.87 (0.80)	4.01 (1.70)	0.64 (0.72)	5.58 (1.96)	4.72 (1.85)	0.46 (0.61)	0.51 (0.63)	22.60 (28.28)
V_2 S_2	11.79 (2.82)	1.65 (1.20)	4.59 (1.86)	0.97 (0.85)	7.79 (2.33)	6.53 (2.21)	0.82 (0.82)	0.84 (0.81)	26.85 (31.07)
LSD (p = 0.05)	0.17	0.06	0.09	0.08	0.15	0.12	0.14	0.07	1.34

()* $\sqrt{x + 0.05}$ transformed values, ()** Angular transformed values

Table 3: Percent bollworm infestation in green fruiting bodies as influenced by cotton hybrid and fertilizer level interaction (V × F) at different crop growth stages and over a season (pooled data: 2008-09 and 2009-10)

V / F	DAS						Over a season
	69-82	83-96	97-110	125-138	139-152	181-194	
V_1 F_1	0.00 (0.22)*	0.00 (0.22)*	0.00 (0.22)*	0.00 (0.22)*	0.25 (0.44)*	0.04 (0.26)*	0.42 (2.85)**
V_1 F_2	0.00 (0.22)	0.00 (0.22)	0.00 (0.22)	0.00 (0.22)	0.10 (0.31)	0.00 (0.22)	0.06 (1.58)
V_1 F_3	0.00 (0.22)	0.00 (0.22)	0.00 (0.22)	0.00 (0.22)	0.09 (0.30)	0.04 (0.26)	0.08 (1.70)
V_2 F_1	9.70 (2.46)	1.24 (1.02)	1.11 (0.90)	0.62 (0.66)	6.13 (2.00)	0.50 (0.59)	22.01 (27.75)

V_2 F_2	11.04 (2.71)	1.48 (1.14)	1.34 (1.01)	0.75 (0.77)	6.93 (2.21)	0.78 (0.76)	25.65 (30.35)
V_2 F_3	10.90 (2.76)	1.48 (1.18)	1.34 (1.09)	1.05 (0.93)	6.99 (2.23)	0.75 (0.81)	26.52 (30.90)
LSD (p = 0.05)	0.12	0.07	0.06	0.07	0.15	0.05	1.87

()* $\sqrt{x+0.05}$ transformed values, ()** Angular transformed values

3.2 Percent loculi damage
The cotton hybrids and fertilizer levels did significant influence on percent loculi damage by *Pectinophora gossypiella*; however, the effect of spacing was found to be non significant (Table 4). Bt cotton hybrid recorded significantly lower percent loculi damage than non-Bt. The lower loculi damage in Bt cotton may be due to the efficiency of Cry protein against pink bollworm. The results obtained in this study corroborate the findings of Ansingkar *et al*. (2005) and Santosh *et al*. (2009), who reported significantly less loculi damage in Bt cotton hybrids over non-Bt cotton hybrids [18, 19]. As regards fertilizer levels, application of 75:37.5:37.5 kg NPK ha^{-1} resulted significantly more loculi damage than lower levels. Higher incidence of *Pectinophora gossypiella* with increasing nitrogen level in cotton was also observed by Bhullar and Gill (2005) [20].

3.3 Seed cotton yield
Data pertaining to seed cotton yield (kg ha^{-1}) presented in Table 4 revealed that, the Bt cotton hybrid recorded significantly higher seed cotton yield than the non-Bt. The higher seed cotton yield in Bt cotton hybrid attributed to more number of picked bolls per plant due to inbuilt resistance to bollworms. The higher yield in majority of Bt cotton hybrids over non-Bt cotton was observed by Patil *et al*. (2009) [21]. The 90 × 45 cm spacing recorded significantly higher seed cotton yield over 90 × 60 cm. The lowest percent bollworm infestation recorded with 90 × 60 cm spacing i.e. at the lowest plant density (18518 plants ha^{-1}) was inadequate to compensate the loss due to plant population and thus resulted in significantly lower seed cotton yield (kg ha^{-1}) over 90 × 45 cm spacing (24691 plants ha^{-1}). Similar result was also reported by Reddy and Kumar (2010) [22].
As regards fertilizer levels, application of 75:37.5:37.5 kg NPK ha^{-1} produced significantly higher seed cotton yield over 50:25:25 kg NPK ha^{-1} but was at par with 62.5: 31.25:31.25 kg NPK ha^{-1}. The significant increase in seed cotton yield with 75:37.5:37.5 over 50:25:25 kg NPK ha^{-1} was the result of associated increase in various growth and yield attributing characters. The present results are in conformity with the findings of Bhalerao *et al*. (2008) [23], they also reported higher seed cotton yield at higher fertilizer level in rainfed situation.

Table 4: Percent loculi damage (by *Pectinophora gossypiella*) and seed cotton yield (kg ha^{-1}) of Bt and non Bt cotton as influenced by spacing and fertilizer levels (pooled data: 2008-09 and 2009-10)

Treatments	Percent loculi damage	Seed cotton yield (kg ha^{-1})
Cotton hybrids		
V_1 Bt Cotton	2.73 (1.59)	1019.68
V_2 Non-Bt Cotton	7.62 (2.74)	900.39
LSD (p = 0.05)	0.12	42.22
Spacing (cm)		
S_1 90 × 60	4.87 (2.18)	902.05
S_2 90 × 45	5.48 (2.15)	1018.03
LSD (p = 0.05)	NS	42.22
NPK levels (kg ha^{-1})		
F_1 50:25:25	4.87 (2.09)	918.63
F_2 62.5:31.25:31.25	4.99 (2.11)	976.96
F_3 75:37.5:37.5	5.67 (2.29)	984.52
LSD (p = 0.05)	0.16	41.33

() Square transformed values

3.4 Impact of abiotic factors
The abiotic factors like weather parameters had significant effect on population dynamics of different crop pests. Hence, for effective weather-pest forecasting it is prerequisite to understand the degree and extent of relationship between weather parameters and pests. The output of correlation analysis between percent bollworm infestation in cotton and abiotic factors are presented in Table 5. During first year (2008-09) of investigation, the percent bollworm infestation in Bt cotton had negative and non-significant relationship with minimum temperature, morning and evening relative humidity and rainfall. Whereas, it showed positive non significant relationship with maximum temperature and BSH. While, in non-Bt cotton positive and significant relationship existed with minimum temperature (r = 0.4349), morning relative humidity (r = 0.4470), evening relative humidity (r = 0.4946) and rainfall (r = 0.4329). Similarly, maximum temperature showed positive but non-significant relationship. But, with BSH negative non significant relationship was noticed. Rao *et al*. (2004) studied the relationship between weather parameters and abundance of *Helicoverpa armigera* in non-Bt cotton; they observed significantly positive relationship between maximum temperature and population of *Helicoverpa armigera* during winter (October month), while minimum temperature showed non significant but positive relationship in this regard. Likewise, significantly positive relationship between morning and evening relative humidity and population of *Helicoverpa armigera* during August was observed by them [24]. This indicates that low temperature considerably slow down the feeding activity and reproduction rates of bollworms and even slight increase in both maximum and minimum temperature resulted population outbreak due to favourable conditions both for feeding and reproduction. Positive correlation between morning relative humidity and bollworm infestation in squares was also reported by Roomi *et al*. (2017) [25].

Table 5: Correlation between percent bollworm infestation and weather parameters

Weather parameters	Correlation coefficient (r)			
	2008-09		2009-10	
	Bt Cotton	Non-Bt Cotton	Bt Cotton	Non-Bt Cotton
Maximum temperature (°C)	0.0558	0.0574	- 0.4408*	0.0508
Minimum temperature (°C)	- 0.0811	0.4349*	- 0.4694**	0.0634
Morning Relative Humidity (%)	- 0.0400	0.4470*	- 0.0183	0.2224
Evening Relative Humidity (%)	- 0.1037	0.4946**	- 0.2354	0.2184
Rainfall (mm)	- 0.1421	0.4329*	- 0.0508	0.0626
BSH (hrs)	0.0037	- 0.2753	0.0861	- 0.3229

*Significant at 0.05 level (r = 0.423) (n = 22) ** Significant at 0.01 level (r = 0.457)

During subsequent year (2009-10) of study, significantly negative relationship was noticed between percent bollworm infestation in Bt cotton and maximum (r = - 0.4408) and minimum (r = - 0.4694) temperature (Table 5). Similarly morning and evening relative humidity and rainfall were also negatively but non-significantly related with percent bollworm damage in Bt. Whereas BSH showed positive but non-significant relationship. In case of non-Bt, all the weather parameters had positively non-significant relationship with percent bollworm infestation except in BSH which had negative and non-significant relationship.

Among all the weather parameters minimum temperature, maximum and minimum relative humidity and rainfall showed a positively significant relationship with percent bollworm infestation in non-Bt cotton during 2008-09. Hence to know the exact nature of relationship between them; a forth degree polynomial relationship was calculated and depicted in figure 1 to 4, respectively. Bollworm infestation in green fruiting bodies increased steadily with increase in minimum temperature from 9 to 22 °C, whereas between 22 to 24 °C it became more or less constant (Fig. 1). Rao *et al*. (2004) [24] observed that larval population of *Helicoverpa armigera* on cotton plant increased with increase in minimum temperature from 23.5 to 25.5 °C however beyond 25.5 °C it decreased. Bollworm infestation gave interesting response to morning relative humidity (Fig. 2). Increase in morning relative humidity from 58 to 67% gradually increased the bollworm infestation while it decreased slightly from 67% onward up 80%. Whereas, increase beyond 80% resulted steep increase in bollworm infestation up to 94%. The rise in evening relative humidity from 8% resulted increase in bollworm infestation and was at its maximum magnitude between 56 to 60%. Thereafter, decrease in bollworm infestation with increase in evening relative humidity up to 79% was observed (Fig. 3). Increase in population of *Helicoverpa armigera* with increase in afternoon relative humidity was observed by Mukherjee and Bhowmik (2009) [26]. Increase in rainfall received in particular week increased the bollworm infestation however rainfall beyond 60 mm showed gradual decrease in this respect (Fig. 4).

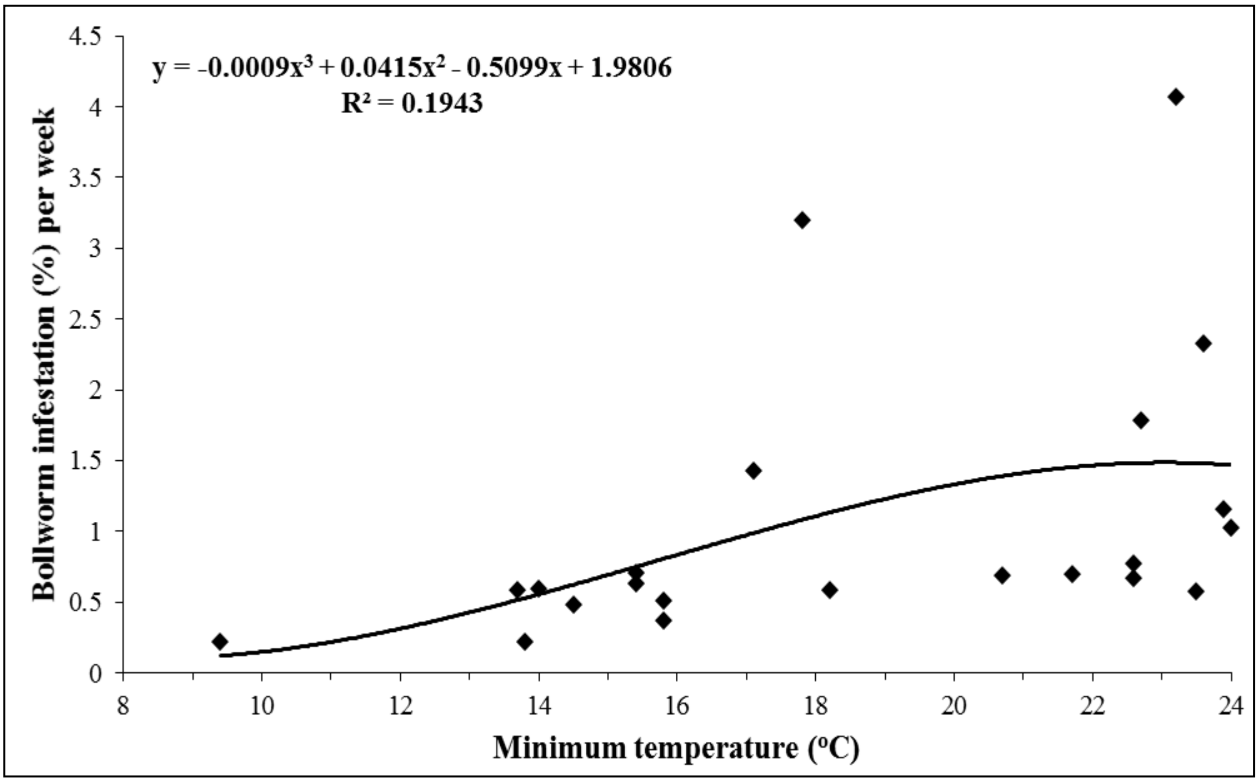

Fig 1: Relationship between percent bollworm infestation in green fruiting bodies and minimum temperature during 2008-09

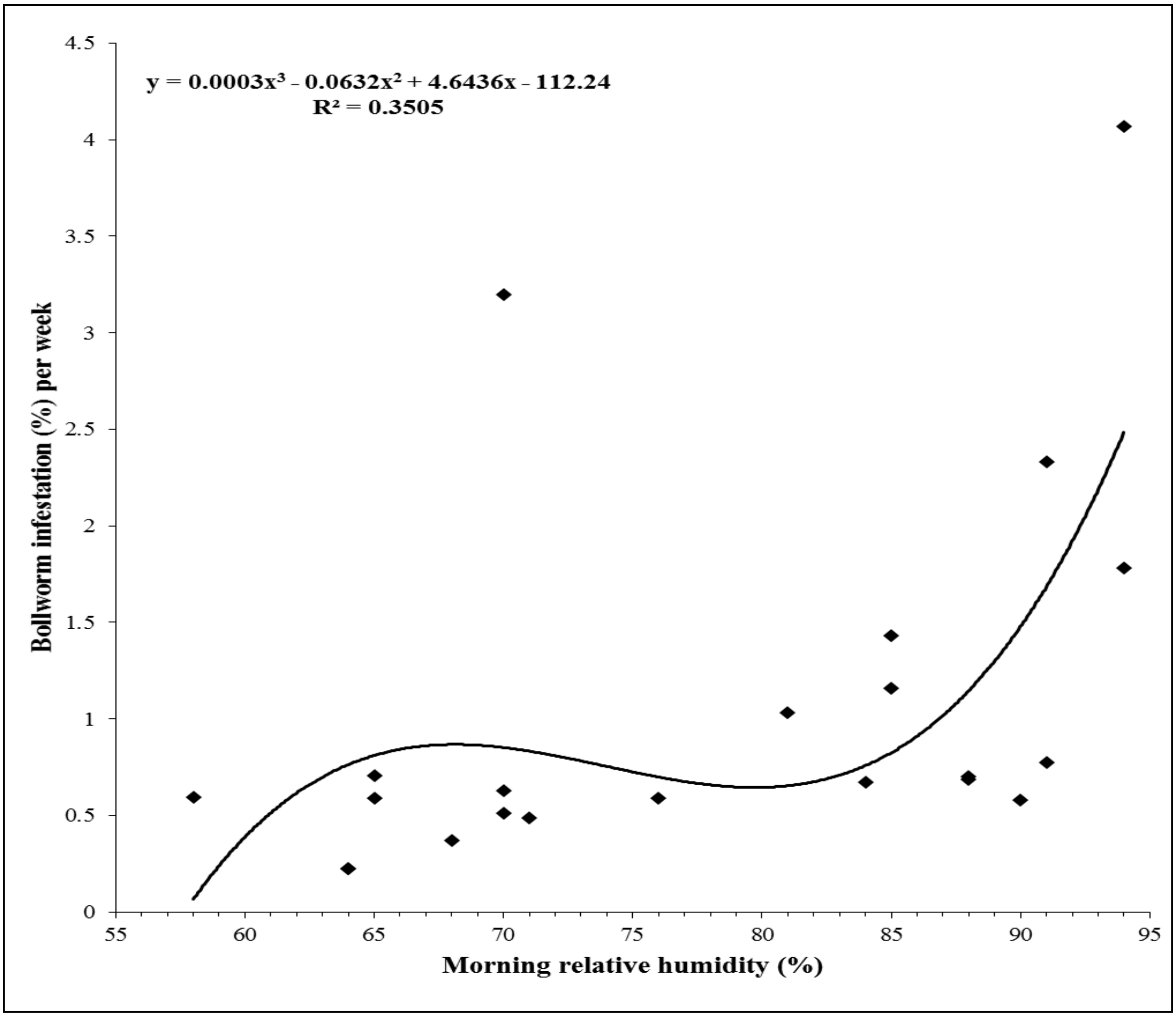

Fig. 2: Relationship between percent bollworm infestation in green fruiting bodies and morning relative humidity during 2008-09

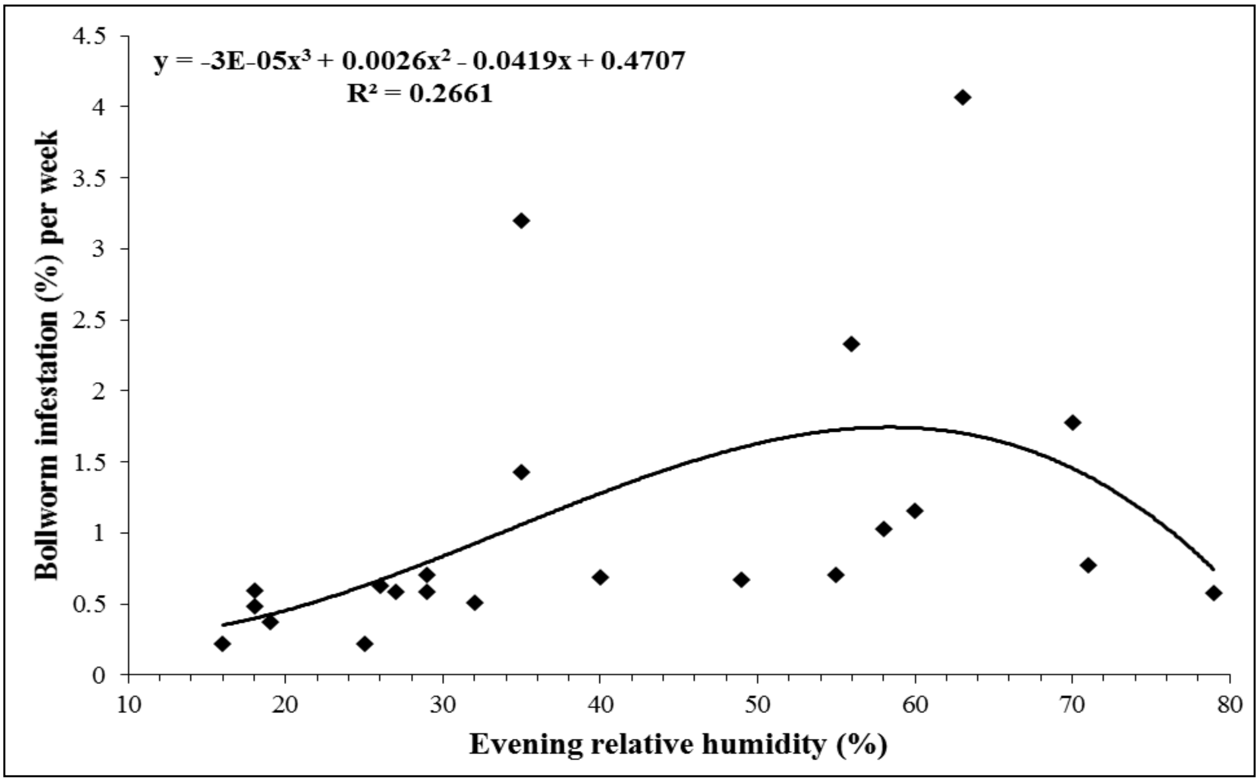

Fig 3: Relationship between percent bollworm infestation in green fruiting bodies and evening relative humidity during 2008-09

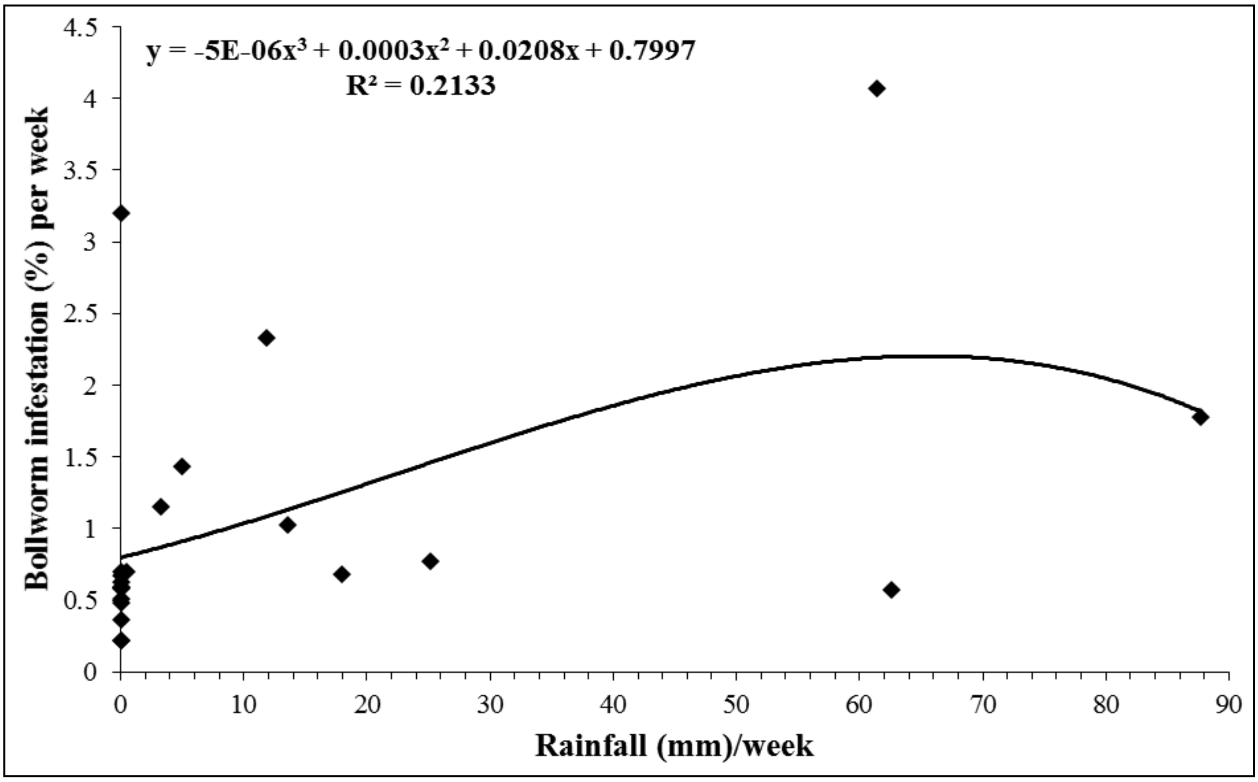

Fig 4: Relationship between percent bollworm infestation in green fruiting bodies and rainfall during 2008-09

After regressing the percent bollworm infestation data of first year (2008-09) with weather parameters, the following multiple regression equation for Bt cotton and weather parameters was obtained.

$Y = - 0.1544 + 0.0046\ X_1 - 0.0025\ X_2 + 0.0022\ X_3 - 0.0009\ X_4 - 0.0004\ X_5 - 0.0094\ X_6$

Where, Y = Percent bollworm infestation, X_1 = Maximum temperature (°C), X_2 = Minimum temperature (°C), X_3 = Morning relative humidity (%), X_4 = Evening relative humidity (%), X_5 = Rainfall (mm) and X_6 = BSH (hr/day)

This multiple regression equation indicate that, for every unit increase in maximum temperature and morning relative humidity would increase bollworm infestation by 0.0046 and 0.0022 units, respectively. Whereas, every unit increase in minimum temperature, evening relative humidity, rainfall and BSH would decrease the bollworm infestation by 0.0025, 0.0009, 0.0004 and 0.0094 units, respectively. The weather parameters influenced the percent bollworm infestation in Bt cotton to the extent of 8.12%.

Multiple linear regression of percent bollworm infestation in non-Bt cotton during 2008-09 with weather parameters was as below. The weather parameters showed 27.14% influence on percent bollworm infestation in non-Bt cotton.

$Y = - 9.7604 + 0.1412\ X_1 + 0.6642\ X_2 + 0.1410\ X_3 - 0.2717\ X_4 + 0.0821\ X_5 - 0.8706\ X_6$

In non-Bt cotton, every increase of one unit of maximum and minimum temperature, morning relative humidity and rainfall would increase percent bollworm infestation by 0.1412, 0.6642, 0.1410 and 0.0821 units, respectively. Whereas, evening relative humidity and BSH decreases by 0.2717 and 0.8706 units, respectively.

The multiple regression equation of percent bollworm infestation in Bt cotton during 2008-09 with all weather parameters was.

$Y = 0.0465 - 0.0015\ X_1 + 0.0002\ X_2 + 0.0004\ X_3 - 0.0005\ X_4 + 0.0002\ X_5 - 0.0022\ X_6$

This equation indicated that, for every unit increase in minimum temperature, morning relative humidity and rainfall would increase percent bollworm infestation by 0.0002, 0.0004 and 0.0002 units, respectively. While, every unit increase in maximum temperature, evening relative humidity and BSH would decrease bollworm infestation by 0.0015, 0.0005 and 0.0022 units, respectively. The weather parameters influenced the percent bollworm infestation in Bt cotton to the extent of 30.58%.

Whereas, multiple regression equation of all-weather parameters with percent bollworm infestation in non-Bt cotton during 2008-09 was.

$Y = - 47.5017 + 1.5028\ X_1 - 1.0034\ X_2 + 0.2813\ X_3 + 0.1237\ X_4 - 0.0301\ X_5 - 1.3736\ X_6$

The above equation indicated that, every unit increase in maximum temperature, morning and evening relative humidity would increase percent bollworm infestation in non-Bt cotton by 1.5028, 0.2813 and 0.1237 units, respectively. But every unit increase in minimum temperature, rainfall and BSH would decrease the same by 1.0034, 0.0301 and 1.3736 units, respectively. The weather parameters showed 48.28% influence on percent bollworm infestation in non-Bt cotton.

Conflicting reports on the influence of weather parameters on bollworm infestation in cotton have been noticed in the literature. However, results obtained in case of non-Bt are in conformity with the findings of Bhatti *et al*. (2007) [27], who also reported positive relationship of temperature, relative humidity and rainfall with bollworm infestation in cotton varieties. The positive relationship of higher incidence of bollworm with higher temperature might be due to higher heat units, which help for development of bollworm and intern quick completion of life cycle.

4. Conclusion

In the present investigation, Bt cotton hybrid exhibited a high level of resistance against bollworms and have higher yield potential than non-Bt. A narrow intra-row spacing of 45 cm was more susceptible to bollworm infestation than recommended spacing of 60 cm but was promising for achieving higher seed cotton yield under rainfed condition. Bollworm infestation, loculi damage and seed cotton yield increased with increasing fertilizer levels. However, gain in seed cotton yield beyond 62.5:31.25:31.25 kg NPK ha^{-1} was non-significant thus was found to be ideal in this respect. Abiotic factors *viz*., maximum and minimum temperature, morning and evening relative humidity and rainfall had positive relationship however; BSH showed negative relationship with bollworm infestation in non-Bt cotton.

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