Review of Literature
II. REVIEW OF LITERATURE

Genetic modification of crops to manage insect pests is a recent approach. Literature on the insect pests population dynamics on Bt cotton is scanty. However, an attempt has been made to consolidate the available literature on population dynamics of insect pests, beneficial insects, insect reaction to Bt cotton, insecticidal protein expression in Bt cotton and finally the economic advantages of growing Bt cotton is presented here.

Population dynamics of insect pests on Bt cotton v/s. non-Bt cotton

Sucking pests

Douglas et al. (1994) reported that as expected, the transgenic lines were not resistant to several non-lepidoterenous insect pests. Higher populations of sweet potato whitefly, Bemisia tabaci (Gennadius) were noticed on the transgenic lines than the control cultivars even under sprayed condition. Unsprayed Bt cotton sustained four times more attack of tarnished bugs and 2.8 times more with stink bugs (Bacheler and Mott, 1996).

Cuijinjie and Jing Yuan (1997) carried out field investigations in China under natural condition. Results showed that seedling and summer aphids (Aphidoidea) and Empoasoa biguttula (Ishida) population increased by 20.3, 21.38 and 67.62% respectively. Whereas, the Thrips tabaci and Trialeurodes vaporariorum (West wood) populations decreased by 39.62 and 39.06 % in transgenic Bt cotton compared to conventional cotton.

Transgenic Bt cottons were field tested during early season under natural condition. Results revealed that the populations of aphids, red spider mite, thrips, whiteflies and leafhoppers increased by 33.1, 138.9, 346, 68.3
and 11.5 % respectively compared to non-Bt cotton (Cuijinjie and Xia Jing Yuan, 1998).

Stewart et al. (1998) suggested that Bt cotton fields may have greater risk of attack by other important pests, such as tarnished plant bugs and boll weevils, therefore these cotton require treatments against them. Xia Jing Yuan et al. (1999) reported *Tetranychus cinnabanus* (Boisduval), *Aphis gossypii* and *Thrips tabaci* replaced *Helicoverpa armigera* as dominant pests in Bt cotton fields.

The number of species, total number and abundance of insect pests on Bt cotton (R93-4) were compared with conventional variety (CCRI-12). Results showed that the red spider mite and cotton aphid became dominant and suggested that where the transgenic variety is planted, monitoring and control measures should be carried out against pasts other than *H. armigera* (Cuijinjie and Xia Jing Yuan, 1999b).

Layton et al. (1998) found that transgenic Bt cotton fields sustained significantly more boll damage due to sucking pests particularly by tarnished plant bugs. Cuijinjie and Xia Jing Yuan (2000b) systematically studied the population dynamics of main pests on Bt transgenic cotton (R 93-4) under field condition. It indicated that the population of sucking pests viz., cotton aphid, greenhouse whitefly and leafhoppers were 25.5, 29.7 and 118.8% respectively, were more compared to non Bt hybrid.

Reed et al. (2000) reported that aphid population appears to be same in transgenic Bt and conventional cotton fields in hills and delta regions of Mississippi. Ning et al. (2001) noticed that population of aphids in the fields of Bt transgenic cotton was slightly higher than that in the field of conventional cotton.
Bt cotton evaluation trials were taken up along with their non Bt versions and check hybrids during the year 2001-2002 under all India Coordinated Cotton Improvement Project (AlCCIP) at central and south zones completely under unprotected condition. It was observed that MECH-162 Bt cotton hybrid had almost same population of leafhoppers (1.69 per leaf) as compared to non-Bt and check hybrids. The population of aphids and thrips on Bt, non-Bt and check hybrids were 7.52, 8.54 and 7.04 per leaf and 8.06, 10.80 and 10.30 per leaf respectively (Anonymous, 2002).

Sun Chang Gui et al. (2002) studied the effect of transgenic Bt cotton on population of cotton pests under natural control. Results revealed that the sucking pests viz., *Aphis gossypii* and *Thrips tabaci* populations increased in Bt cotton fields compared to normal cotton fields. James (2002) noticed no differences in population of sucking pests such as aphids, jassids and whiteflies between Bt and non Bt hybrids.

Wu et al. (2002) noticed no differences between population densities of mirid bugs in Bt and non-Bt cotton fields. However, mirid damage was significantly higher in transgenic unsprayed cotton compared to normal sprayed cotton. It indicated that mirids have become key insect pests in transgenic cotton fields and their damage could increase further if no additional control measures are adopted.

**Bollworm complex and their damage**

Transgenic lines of cotton which carry one of two insect control protein genes from *B. thuringiesis race kurstaki* (Berliner), Cry 1 A (b) and Cry 1 A(c) showed high levels of resistance to several lepidopteron insects (Benedict et al., 1991; Wilson et al., 1992).
Douglas et al. (1992) evaluated transgenic cotton for resistance to several lepidopteron insects along with locally adopted control. Results revealed that early in the season, before bolls were available for infestation the number of rosette blooms caused by pink bollworm, was 95% lower in transgenic line than in the control. Benedict et al. (1993) inoculated 100 eggs of Helicoverpa armigera on transgenic lines and non-expressing Cocker 312 under green house condition. They noticed two and six percent damaged flower buds and bolls on transgenic cotton compared to 34 and 54% on control.

The non-Bt cotton received an average of 5% more insecticide treatments against the bollworm complex compared with no applications for the Bt cotton (Davis et al., 1995). The season mean percent injury on the flower bud and carpels were 23 and 1.1 per cent in Bt cotton lines. The numbers of cabbage loopers were also lower in Bt cotton lines (Benedict et al., 1997).

Halcomb et al. (1996) found that the number of eggs in terminals did not differ between Bt and non Bt cotton. However, the number of injured flower buds, bolls and terminals and the number of larvae were more in non transgenic cotton compared to Bt cotton fields.

Transgenic Bt cotton provided excellent control of bollworms. Helicoverpa zea (Boidde), tobacco budworm, Heliothis virescens (Fabricius) and cabbage looper, Trichoplusia ni (Hubner) in large field plots (Cuijinjie and Xia Jing Yuan, 1997a). Worley et al. (1996) reported that Bt cotton provided effective control of Heliothis virescens throughout the season and larval populations were reduced by 40-60% during July and August months. The amount of population reduction observed in the Bt cotton was much more
than the non-Bt cotton. Mahdavi (1997) made observations on large commercial scale Bt cotton field in 1996 and initial results showed that transgenic plants were not entirely protected against bollworms. However, he concluded that transgenic variety was benefit to farmers.

Wang Chunyi and Xia Jing Yuan (1997) observed that the incidence of noctuid eggs in both (Bt and non Bt) kinds of fields was almost same when the area of Bt transgenic cotton fields was small, whereas the population of bollworm larvae showed significant difference. Cuijinjie and Xia Jing Yuan (1998) confirmed transgenic cotton fields were highly resistant to Heliothis armigera and Anomis flava (Fabricius), with numbers of other insect pests remaining below the prevention index.

The transgenic Bt cotton fields sustained significantly less larvae induced boll damage than non Bt fields (1.86 against 2.73 per cent) and received fewer treatments targeting bollworms (Helicoverpa zea) and tobacco budworm (Heliothis virescens), 0.86 as against 3.14 foliar spray per acre (Layton et al., 1998; Layton et al., 2000).

Leonard (1998) and Zhao Jian Zhou et al. (1998) observed that larvae developed from eggs deposited within the plant canopy, particularly flowers and squares are difficult to control because of their location and size. Due to this reason they cause boll damage on Bt cotton. Tol et al. (1998) observed crop terminal to detect Heliothine (H. vrescens and H. zea) populations. Results showed significantly less number of larvae and damage to squares in Bt cotton fields as compared to non Bt cultivars.

Nava Camberos et al. (1999) found that there was no spring emergence of pink bollworm or it was very low on Bt cotton. Spring emergence was considerably reduced in those areas where Bt cotton was
planted in the previous year and highlights the low infestation levels of pink bollworm and reduction of insecticides use. Xia Jing Yuan et al. (1999) reported transgenic Bt cotton was highly resistant to *H. armigera*, but the degree of resistance fluctuated in time and space.

Cuijinjie and Xia Jing Yuan (2000b) studied the effects of Bt transgenic cotton on the dynamics of pest population. Results showed that Bt cotton was highly resistant to cotton bollworm (*H. armigera*) and cotton semi-looper (*Anomis flava*) and their peak larval populations were significantly smaller than those on the control non Bt variety, although there was still a need to adopt additional chemical control against cotton bollworms in its 3rd and 4th generations.

Ghosh (2000) reported that results obtained in the fields showed Bt cotton provides excellent control of the key caterpillar pests in Indian cotton fields, such as the American bollworm (*H. armigera*), spotted bollworm (*E. vittella*), spiny bollworm (*E. insulana*) and pink bollworm (*P. gossypiella*). Henneberry et al. (2000) collected bolls from artificial pink bollworm egg infested fields, they found that both Bt and non Bt cotton bolls had numerous larval entrance holes in the carpel walls of the bolls, less than one per cent of the Bt cotton bolls and over 70 per cent of the non Bt cotton bolls had living pink bollworm larvae.

Pink bollworm infestation of 17.2 per cent in the open mature bolls and 10.5 per cent in the immature green bolls in conventional hybrid (DPL-5415) and zero per cent in the open mature bolls and 1.7 per cent in the immature green infested bolls in Bt cotton hybrid was reported by Henneberry and Jech (2000), Nava Camberros et al. (2000).
Sumer Ford and Solomon (2000) noticed significantly fewer larvae of soybean looper (*Pseudoplusia includens*) in Bt cotton fields than non Bt cotton fields. Wu *et al.* (2002) reported that the area planted under Bt cotton in northern region of China has continuously expanded and there has been a corresponding decrease in damage to cotton by *H. armigera*. These transgenic cottons have a great promise in controlling cotton bollworms.

Adamezyk *et al.* (2001) sampled lepidopteron insects (three samples / plant) using 1.2 m² drop cloth. Results indicated that the mean number of beet armyworm, tobacco budworm and soybean looper were 6.0, 0.0, 0.25 respectively on Bt cotton as against 21.7 and 32 in conventional variety. Ghosh (2001) reported that transgenic Bt cotton provides no control during the egg laying by lepidopteron pests. However, larval populations of bollworm complex were low in Bt hybrids compared to non Bt. The Bt cotton hybrids registered significantly less damage to the fruiting bodies and superiority in yield over the non Bt counterparts.

Hu *et al.* (2001) reported that the average percentage of highly damaged leaves by *Apocheima cinerarius* and *Orthosia inserta* on the transgenic 'popular tree' (*Populas nigra*) was 10 per cent while that on the control trees reached 80-90 per cent. James (2002) observed significantly less bollworm larvae on Bt cotton hybrids as compared to their non-Bt counterparts during the two periods 0-60 days (1.2 against 6.1 larvae / plant) and 61-90 days (1.7 against 7.4 larvae / plant) after sowing.

Ning *et al.* (2001) confirmed that Bt cotton had better bollworm (*H. armigera*) resistance. The egg mass in the field of Bt cotton was not different from that in the field of conventional cotton, indicating that the Bt toxin did not deter oviposition. Kong Ming *et al.* (2002) counted larval densities of *H.*
armigera and results showed 960 and 20,480 larvae per ha during 1999 and 8000 and 97,600 larvae per ha during 2000, in Bt and common fields respectively. Tracey et al. (2002) evaluated transgenic corn against European corn borer, O. nubilalis (Hubner) damage and gain yield in commercial plots across Ontario, Canada during 1996 and 1997. The results showed Bt corn hybrids reduced stalk tunneling by 88-100 per cent. European corn borer infestations resulted only 2.4 per cent yield reduction in Bt corn when compared to its non-Bt isoline.

Transgenic Bt cotton hybrids registered significantly lower population of H. armigera ranging from 0.3 to 0.77 larvae per five plants, while it was significantly higher and ranged from 1.57 to 2.97 and 2.92 to 3.92 larvae per five plants in non Bt and check hybrids respectively (Surulivelu et al., 2003).

Yuan et al. (2003) conducted 3-year field experiment to know the effects of Bt transgenic cotton on diversities of arthropod communities. The results indicated that Bt cotton increased the diversity of arthropod communities; but decreased the diversities of natural enemy sub communities. However, Yuan and Ming (2003) reported the resistance of cotton aphids to majority of insecticides used for control of H. armigera and lower densities of predators caused by insecticide use resulted into significantly higher densities of aphids, A. gossypii on conventional cotton than Bt cotton. This clearly indicates planting of Bt cotton not only controlled H. armigera but also efficiently prevented cotton aphid resurgence.

Field evaluation of Nu COTN 33 B in China showed there is no significant difference in egg densities of H. armigera on the Bt cotton cultivars and non-transgenic varieties during the season, although the survival of larvae on Bt cotton reduced significantly (Knong Ming et al., 2003).
Sisterson et al. (2004) reported that the arthropod abundance did not differ significantly between Bt and non-Bt plants except for bollworms. Leafhopper population on Bt cotton plants were consistently higher than those on non Bt cotton during 3 year field studies conducted by Men et al. (2005).

Population dynamic of beneficial fauna on Bt cotton v/s non-Bt cotton

There were no significant differences in the total number of natural enemies of cotton pests recorded in transgenic Bt cotton and non-Bt cotton (Cuijinjie and Xia Jing Yuan, 1997b; Wang Chunyi and Xia Jing Yuan, 1997; Tol et al., 1998; Cuijinjie and Xia Jing Yuan, 1999b).

Pilcher et al. (1997a) studied the field abundance of insect predators on transgenic Bt corn. Results showed that populations of Coccinellid grubs and adults, Chrysopid eggs and adults, adult Anthocorids and Arachnids were 0.6 and 0.13; 2.3 and 0.03, 0.93 and 0.50 per plant respectively in Bt corn fields as compared to 0.2 and 0.2, 1.73 and 0.03, 1.36 and 0.46 per plant in non-Bt corn fields.

Cuijinjie and Xia Jing Yuan (1998) observed that the populations of predators viz., spiders, Chrysopa, Anthocorids were decreased by 3.6, 20.0 and 30.4 per cent respectively. Whereas, the Propylea japonica (Thunbory) population was increased by 11.8 per cent on Bt cotton as compared to control.

Armstrong et al. (2000) worked out the density of predatory insects and spiders from large acreage of cotton producer fields. Insect and spider predators were grouped as those with chewing mouthparts and piercing -sucking mouthparts. Among piercing sucking predators minute pirate bug, Orius tristicolor (White), Big eyed bugs, Geocoris punctipes (Say) and cotton
leafhopper, *Pseudotomoscelis seriatus* (Reuter) contained 89 per cent of the total number of piercing sucking predators in Bt cotton fields and 90 per cent of those collected in non-Bt cotton. Among chewing predators *Arnaeae, Coccinellidae* and *Notoxus* spp accounted 91 per cent and 96 per cent in Bt and non-Bt cotton fields, respectively.

Liu *et al.* (2000) reported that the predator, *Campylomma diversicornis* (Reuter) had four generations. The first generation occurred on weeds around the cotton field and other generations on cotton. It preys on eggs and newly hatched larvae of *H. armigera* in mid to late cotton growing stages especially on transgenic Bt cotton fields.

Mohammad *et al.* (2001) counted the predator, *Orius inisdiosus* (Say) nymph and adults on Bt cornfields during 1999 at Manhattan, Kansas. The population of nymphs and adults were 2.0 and 0.8 and 1.5 and 1.1 per plant on Bt and non-Bt cornfields respectively. Baoping *et al.* (2002) reported transgenic crops are non-toxic to natural enemies and no detrimental effects were observed on beneficial organisms. The population of predators and parasitoids in transgenic cotton, maize and potato lines are equal or higher than those in regular crop fields.

Chaufaux *et al.* (2002) compared the temporal abundance of non-target arthropods like, *Orius isidiosus, Syrphus corollae* (Fab.) and *Coccinella septempunetata* (Linn.) on Bt and non-Bt corn fields. Studies also revealed that the number of individuals varied greatly over the season but did not differ between the types of maize.

The predator, *Chrysopa formosa* (Brauer) populations increased and *Orius minutus* (Linn.) decreased in number in transgenic cotton fields as compared to normal cotton fields (Sun Changgui *et al.*, 2002).
Results obtained by Kong Ming et al. (2003) indicated a significantly higher predator levels in Bt cotton fields than there in conventional cotton fields where insecticides were sprayed for control of bollworms. However, population density of parasitic wasps that parasitize bollworms decreased dramatically due to lower densities and poor quality of bollworms in Bt cotton fields.

Hui et al. (2003) reported that Bt cotton negatively affected the development of *Apanteles ruficrus* (*Cotesia ruficrus*), which is a parasitoid of cotton leaf roller, *Sylepta derogata*. Another study conducted by Chang Gui et al. (2003) showed a significantly lower population density of majority of natural enemies (predators and parasitoids) in Bt cotton plots than in normal cotton plots.

**Insect reaction to season long expression of Cry1Ac insecticide protein in Bt cotton**

Three Bt lines and their recurrent non-Bt lines as well as conventional variety (Cocker – 312) were grown. Results indicated that Bt cotton lines provided excellent control of tobacco budworm without the need for externally applied insecticides. A very high level of tobacco budworm damage was seen in non-Bt lines (Jenkin *et al.*, 1995).

Allen *et al.* (1998) conducted a field study to test the varietal performance. The results indicated that Bt cotton although not immune to bollworm damage, were resistant to damage. Scouting and spraying Bt cotton as needed can gain economic benefits. Leonard *et al.* (1998) reported that all Bt cotton lines controlled the bollworm (*Helicoverpa zea*), tobacco budworm (*Heliothis virescens*) complex and produced seed cotton yields more than their non Bt lines in both non sprayed and sprayed conditions.
Obandorodrigues *et al.* (1999) reported Bt cotton varieties (DP 33B and DP – 35B) had good control of bollworms and demanded fewer insecticidal applications as compared to the conventional variety (DP 5690). Between two Bt cottons, DP – 33 B had the highest yield. Zhao Jian Zhou *et al.* (2000) conducted field studies to know the insecticidal activity of Bt cotton lines. Four transgenic Bt cotton lines viz., GK – 12, GK-2, R- 108 (from China) and NuCOTN 33B (from Monsanto, USA) were screened against *H. armigera*. Among the four Bt lines GK – 12 and NuCOTN 33 B showed much higher insecticidal activity against *H. armigera*.

Davison *et al.* (2001) screened transgenic potato lines (D53 and D62) against potato tuber moth in New Zealand. Results indicated that both transgenic lines recorded significantly fewer mines on the foliage as compared to non-GM lines. Further the incidence of mines recorded on transgenic lines decreased through time, while the pest incidence on the control plants remained high and relatively constant throughout the season.

Transgenic Bt cotton (MECH series) evaluation trials were taken up along with their non Bt versions and check hybrids during the year 2001-2002 under All India Co-ordinate Cotton Improvement Project (AICCIP) at the central and south Zones, completely under unprotected condition. Results indicted that all MECH hybrids were susceptible to sucking pests. Among them MECH-12 Bt was more susceptible to jassids (4.33 per leaf) followed by MECH-162 Bt (2.33 per leaf) and MECH-184 Bt (1.7 per leaf). Whereas, aphid populations were more in MECH –162Bt (7.52 per leaf) followed by MECH-184Bt (6.35 per leaf) and MECH-12Bt (5.8 per leaf). However, the data on *Helicoverpa* and *Earias* larval populations clearly differentiated differences between Bt and non-Bt cotton hybrids. The mean number of *Helicoverpa* larval populations ranged from 1.2 to 2.8 per five plants and 3.6
to 7.8 larvae per five plants in Bt and non-Bt fields, respectively. Between Bt hybrids MECH-184 recorded less number of larvae (1.2 / 5 plants) compared to MECH-12Bt (2.1 larvae / 5 plants). Similar was the trend with respect to *Earias* population which ranged form 0.23 to 0.65 and 1.2 to 2.52 larvae / 5 plans on Bt and non-Bt fields respectively. The mean open boll damage ranged from 15.32 to 25.58, 31.6 to 47.1 and 51.3 to 52.2 % in Bt, non-Bt and check hybrids respectively. Whereas, locule damage in Bt hybrids ranged from 16.54 to 23.21 per cent as compared to 31.01 to 47.47 per cent in non-Bt and 18.41 to 32.36 per cent in check hybrids (Anonymous, 2002).

Badrinarayanan (2002) observed percent boll damage in Bt and non-Bt cotton fields under unprotected condition. Results showed 4.9, 4.4 and 2.2 per cent boll damage in MECH-12, MECH-162 and MECH-184Bt, respectively as compared to 6.9 , 6.3 and 6.6 per cent boll damage in MECH-12, MECH-162, and MECH-184 NBt hybrids respectively.

Hariprasad Rao *et al.* (2002) conducted field trials at Agricultural Research Station, Warangal, Andra Pradesh and the results revealed the usefulness of the new technology against *H. armigera* up to 100 days of sowing. Further, the Bt cottons have not shown any resistance to sucking pests and in fact the jassid buildup was more on Bt cotton hybrids as compared to their non-Bt versions. Results also showed MECH-162 Bt suitability for late sown condition, while MECH-12 and MECH-184 Bt were found to perform well under timely sowings.

Udikeri *et al.* (2002) carried out field experiment at agricultural Research station, Dharwad, Karnataka during kharif 2001-2002 to assess the performance of three Bt transgenic hybrids (MECH-12, MECH-162 and MECH-184) under unprotected condition. Results indicated that the presence of Cry
1Ac protein in cotton hybrid resulted in much variation in the incidence of bollworms. The Bt hybrid MECH-184 registered significantly lower incidence of *H. armigera* (0.91 larva per plant) followed by MECH-162 Bt (1.05 larvae per plant). The population of spotted bollworm larvae ranged from 0.06 to 0.08 per plant. It also indicated that there was no effect of Bt toxin on any of the sucking pests. Per cent damage to fruiting bodies were 4.04, 5.02 and 6.84% on MECH-184, 162 and 12Bt hybrids respectively.

Mahabaleshwar Hegde *et al.* (2003) screened cotton genotypes, MECH-12, 162 and 184 Bt with their respective non-Bt versions, regional check (savitha) and national check (NHH-44) at Agricultural Research Station, Siruguppa, Karnataka. All genotypes were sprayed uniformly for sucking pests and no spray was given for bollworms. Results revealed that cotton genotypes bearing Bt gene recorded significantly lower *E. vittella* damage to growing shoot and boll damage. All Bt genotypes recorded very low locule damage as compared to the non-Bt types. Number of good opened bolls per plant was highest in MECH-184 Bt than the remaining Bt and non-Bt types.

Murugan *et al.* (2003) did laboratory evaluation of the efficacy of Bt cotton cultivars. Results showed after 72 h feeding an Bt cotton cultivars Mech 12 Bt, Mech 162 Bt and Mech 184 Bt, the early instars of *H. armigera* recorded 92.8, 66.7 and 51.7% mortality at first, second and third instar stages, respectively. The first instar larvae suffered with high mortality on all four plant parts tested, namely top leaf, middle leaf, square and boll of the transgenic cultivars.

Meng Feng Xia *et al.* (2003) reported that the efficacy of the leaves from second to the tenth nodes on the main stem of Bt cotton R19-137 was
the highest, killing 97-100% of larvae after 5 days feeding with 1.0-1.1 grades of leaf damage. The efficacy of the leaves from the eleventh to the sixteenth nodes decreased significantly with mortalities of 35.6 – 67.6% and the survivors mainly in the second instar. When leaves from lateral branches of cotton were tested, mortalities of 30.9 – 44.9% and 10.0 –30% occurred, respectively, indicating further decline of the control efficacy. The experiment showed significant influence of weather conditions, under which Bt cotton grew, on the control efficacy of its leaves.

The difference in Bt gene expression in different cotton lines reduced gradually from the 2nd to the 4th generation of bollworms. The level of Bt gene expression in transgenic Bt lines decreased with the development period of cotton (Yi et al., 2003).

Adamczyk and Meredith et al. (2004) reported that the amount of Cry1Ac delta endotoxin in transgenic cotton plants varies among commercial cultivars. These differences in expression have been correlated with survival levels in Lepidoptera, indicating that all Bt cultivars do not provide same level of control.

Results of the experiment by Wan et al. (2005) showed that the Cry toxin content in Bt cotton changed significantly over time, and the structure, growth stage and the variety. Insecticidal protein levels were high during the early stages of crop growth, declined in mid season and renounced in late season of the crop growth. Toxin content in leaf, square, petal and stamens were much higher than those in ovule and boll.

Cost benefits of growing Bt and non-Bt cotton

Douglas et al. (1994) screened nine transgenic cotton lines along with non-Bt and locally adopted nectarines (MD-51ne) variety under natural
condition to assess the yield and yield components of transgenic lines. Results of three years showed that, mean lint yield of transgenic lines was 135.4 + 4.5 g / mt², in Cocker 312 was 115 + 7.7 g / mt² and it was 141.2 + 11.4g / mt² in local check 9MD-51 ne).

Jenkin et al. (1995) reported the mean yield of 1686 pounds of lint per acre in Bt lines when compared to 1546 pounds of lint per acre in non-Bt lines.

Benedict et al. (1997) screened Bt cotton lines under unprotected condition and recorded yield. The average yield of Bt lines was 1460 kg/ha as against 1050 kg/ha in non-Bt lines. Ghosh (2001) reported that the benefit of Rs. 5469, Rs. 750 and Rs. 1014, respectively from Bt, non - Bt and national check cotton hybrid in one acre area.

Transgenic Bt cotton yield ranged from 7.56 to 17 q/ha as against 4.27 to 5.61 q/ha in non-Bt counterpart and in check it ranged from 3.85 to 11.1 q/ha. Net income of Rs. 23787, Rs. 12221 and Rs. 11257 were obtained from Bt (MECH-184), local check (savitha) ad national check (NHH-44) hybrids respectively, in one hectare area (Anonymous, 2002).

Bennet et al. (2003) revealed a direct cost benefit for Bt cotton growers ($51) per hectare per season due to the reduction in number of insecticide applications. Cost savings emerged in the form of lower requirements for pesticides but also important were reduced requirements for water and labour.

Field trials with Bt cotton conducted in India showed, one third reduction in amounts of pesticides used compared to conventional cotton, while under sever pest pressure yield gains were 80% (Qaim, 2003). A comparative analysis of conventional and Bt cotton varieties done at
Argentina provided benefits such as increased crop yield and a considerable reduction in number of insecticide applications. The average additional benefit obtained was $57.98 / ha (Bianconi, 2003).

Surveys conducted by Hezhang et al. (2004) in China proved significant gains in net revenue to farmers growing Bt cotton as a result of reduced production costs. However, yield increase compared to the non-Bt cotton varieties with good management and pesticide applications was marginal. Morse et al. (2004) reported significant, substantial and consistent benefits of adopting Bt cotton for resource poor smallholders. The benefits were largely in the form of increased yields, reduced pesticides and labour for spraying that, despite higher seed and harvesting labour costs.

Bambawale et al. (2004) reported that there was a significant reduction in bollworm incidence and the damage caused by them to the fruiting bodies in Bt cotton compared to conventional cotton with IPM. Seed cotton yield (12.4 q/ha) and net returns (Rs. 16231/ha) were higher in Bt cotton than conventional cotton with a yield of 7.1 q/ha and net returns of Rs. 10507.