BT COTTON TOLERATES DAMAGE AS WELL AS CONVENTIONAL COTTON

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SUMMARY

Has the introduction of Bt genes into the cotton plant affected its capacity for compensation after insect damage? This question is relevant for three reasons. First, and most obviously, Bt cottons remain vulnerable to non-lepidopteran pests, including thrips and mirids. Second, they are susceptible to *Helicoverpa* spp. when Bt efficacy drops because of crop ageing. Third, under some (yet undefined) environmental conditions, Bt efficacy can be low even in young crops, and we have seen fruit shedding in young commercial Bt crops that has been attributed to *Helicoverpa* damage. We assessed the degree of tolerance of Bt cotton to actual and simulated insect damage in three field experiments carried out at ACRI in 1996/97. Yield and maturity responses to damage of Bt cottons compared well with those of conventional varieties. The introduction of Bt genes into cotton does not seem to have reduced the considerable capacity of the crop to tolerate insect damage, and this attribute should be considered in the development of pest management strategies for Bt crops.

Introduction

Bt cottons provide a platform for cropping systems that are less dependent on chemical control of *Helicoverpa* spp. The overall performance of Bt cotton has been evaluated in a series of field trials and commercial Bt varieties have already been released in the U.S.A. and in Australia. The capacity of Bt crops to tolerate insect damage has not been, however, explicitly examined.

The tolerance to damage or "compensation" of Bt cotton is important for three reasons. First, and most obviously, Bt crops are vulnerable to non-lepidopteran pests, including thrips and mirids. Second, Bt efficacy declines, and the susceptibility of the crop to *Helicoverpa* increases, during the period of boll maturation. Third, under some (yet undefined) environmental conditions, the efficacy of Bt toxins can be low even in young crops; during the last season we have seen fruit shedding in young commercial Bt crops that has been attributed to damage by *Helicoverpa*.

We know that conventional cottons have a fairly good capacity to recover, within certain limits, after episodes of insect damage. The introduction of foreign genes into the plant might have changed, for better or worse, this capacity - we don't know. This study assessed the tolerance of Bt cotton crops to damage caused by insect and simulated damage.

Methods

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Three experiments were carried out at the ACRI in the 1996/97 season to assess the response of Bt cotton to (a) naturally occurring populations of *Helicoverpa* spp (Experiment 1), and (b) simulated insect damage including tipping out, as caused by Helicoverpa, mirids and heavy thrips infestation, and/or fruit loss, as caused by *Helicoverpa* and mirids (Experiments 2 and 3). Crops were timely sown (10-14 October), well fertilised (150 kg N/ha), treated with aldicarb to control thrips, and fully irrigated. The soil in Exp. 1 was more sodic and of lighter texture, hence more prone to waterlogging, and less favourable for mycorrhizal colonisation than the soil in Experiments 2 and 3. These proved to be important differences influencing crop responses to damage. Table 1 summarises the treatments and issues addressed in each experiment.

Results

Experiment 1

The density of *Helicoverpa* spp. eggs was unaffected by variety (Siokra V15 vs Sicala V2, Bt vs conventional) or spraying regime (S1 vs S2). Across treatments, it averaged 1 ± 0.2 eggs per m^2 before boll set (< 100 DAS) and 5.3 ± 1.4 eggs per m^2 afterwards. Cumulative number of larvae weighed by their sizes was calculated to quantify survival (mm of larvae per m of crop row). As expected, survival of larvae was significantly lower in Bt crops than in conventional crops and it was also lower in crops more frequently treated with insecticide (S1 vs S2). Before boll set, for instance, the most protected crop (Bt, S1) had a survival of 0.7 mm of larvae per m compared with the conventional, S1 which had 3.6 mm of larvae per m.

Vegetative growth was unaffected by treatments but boll set and boll opening were delayed in the least protected treatment (conventional, S2) in comparison with the most protected treatment (Bt, S1). Yield was measured when the most protected, earliest crop, was ready for picking. Irrespective of the background (Sicala V2 or Siokra V15), the yield of fully sprayed (S1) Bt crops was close to 10.7 b/ha. The ranking of treatments, based on yield measured in $2m^{-2}$ samples agreed with the ranking based on lint yield picked in 0.11 ha plots (S. Deutscher, unpublished data): Bt S1 > Bt S2 = conventional, S1 > conventional, S2 (Table 2).

The number of green bolls per m^2 remaining in the crops at the end of the season was: 7 in Bt S1, 15 in Bt S2, 15 in conventional S1, and 24 in conventional S2. Taking seed cotton of mature and immature bolls together as a measure of total yield potential, i.e if all crops been allowed to contiue to develop to maturity, no differences were found between Bt and conventional crops and the effect of insecticide treatment was less (13% difference between S1 and S2). This highlights the potential ability of cotton crops to compensate for damage, and the importance of time available for recovery as a key determinant of actual compensation.

Experiment 2

Despite delays in squaring and boll set caused by damage treatments, all crops had the same final number of open bolls. Differences in boll weight were significant at 65 DAS, reached a maximum at 100 DAS and disappeared at 155 DAS. Yield was unaffected by damage treatments but the maturity of the more severely damaged crops was delayed by about a week.

Experiment 3

Removing 50% of the squares present in the crop had dramatic but transient effects on cotton development. At 140 DAS, W1-W3 crops had only 2-6% of plants with open bolls in comparison with the controls that had 20% of plants with open bolls. Crops recovered, however, and all yielded the same, irrespective of damage treatments. Damaged crops tended to reach maturity later than the undamaged control but differences were not significant. The responses of these Bt crops were therefore consistent with the responses of conventional cotton which, according to Gibb (1995), don't lose yield provided they reach 50-60% fruit retention.

Implications for pest management in Bt crops

Bt cotton provides a basis to reduce the use of insecticides aimed at *Helicoverpa* spp. Previous studies have shown a consistent decline in the efficacy of Bt toxins during the last part of the growing season, and some cases of reduced efficacy early in the season have also been observed in commercial Bt crops. This, together with the obvious need to protect the crops against non-lepidopteran pests, means that information on crop tolerance to damage is important to devise effective pest management strategies for Bt crops.

Studies of tolerance to damage in conventional cotton demonstrated (see references in Table 3):

- That crop yield is unlikely to be reduced by tipping out similar in timing and intensity to those investigated in Exp. 2.
- A substantial capacity of the crop to recover after fruit loss similar to that in Exps 1-3.
- Important influences of growing conditions on the actual degree of compensation.

Experiments 2 and 3 indicate that the degree of tolerance to early-season tipping out and to fruit loss in Bt crops is comparable to that usually observed in conventional crops (Table 3). The full yield recovery of damaged crops in Exps 2 and 3 contrasts with the results of Exp. 1, in which Bt crops with six insecticide applications yielded less than their counterparts with nine insecticides (Table 2). This was attributed to two major differences between experiments (Sadras 1998): (a) poor soil conditions in Exp. 1 that delayed crop growth with the consequent reduction in the duration of time available for recovery, and (b) the continuous insect pressure to which crops were exposed in Exp. 1 compared to the discrete damage episodes of Exps 2 and 3.

If this interpretation of results is correct, single episodes of damage causing up to 50% square loss due to larvae that escape the effects of Bt toxins should not be of great concern unless: (a) this situation persists causing multiple episodes of fruit shedding and/or other non-lepidopteran pests, such as mirids, also damage the crop or (b) crops are grown in stressful conditions, such as poor soils, that slow down development and restrict time available for recovery.

This is the first study of tolerance to damage in Bt cotton and certainly the responses of the crop to damage could be expected to be influenced by factors such as genetic background, nitrogen supply, water availability, temperature, radiation and interactions between pests (e.g. early damage by thrips x late damage by *Helicoverpa* spp). Studies specifically designed to investigate the interactions between these factors and the crop are required. In principle, the experiments discussed in this paper indicate that the introduction of Bt genes into cotton did not reduce the considerable capacity of the crop to tolerate insect damage, and this attribute should be considered in the development of pest management strategies for Bt crops.

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Table 1. Summary of experiments

Treatments	Question asked
Experiment 1	How do Bt varieties respond to actual Helicoverpa spp. damage in comparison to conventional varieties?
Sicala V2, S1[A]	
Sicala V2*i*, S1	
Sicala V2, S2	
Sicala V2*i*, S2	
Siokra V15, S1	
Siokra V15*i*, S1	
Siokra V15, S2	
Siokra V15*i*, S2	
Experiment 2[B]	How do Bt varieties respond to tipping out, square loss, and the combination of tipping out and square loss?
C: undamaged control	
V: manual tip out at 36 DAS[C]	
R1: total square removal at 64 DAS (removed: 25 sq m^{-2}),	
R2: removal of randomly chosen 25 sq m^{-2} at 71 DAS	
V+R2: tip out as in V + square removal as in R2	
Experiment 3[B]	How do Bt varieties respond to timing of square loss?
C: undamaged control	
W1: 50% of squares removed one week after beginning of squaring	
W2: 50% of squares removed two weeks after beginning of squaring	
W3: 50% of squares removed three weeks after beginning of squaring	
W4: 50% of squares removed four weeks after beginning of squaring	
W5: 50% of squares removed five weeks after beginning of squaring	

[A]S1: 9 insecticide sprays to control Helicoverpa (using thresholds recommended for conventional cotton), S2: 6 sprays, thresholds recommended for Bt crops. [B]Experiments 2 and 3 were carried out in crops of Sicala V2i protected with insecticides using thresholds recommended for conventional cotton. [C]Days after sowing.

Table 2. Lint yield in Exp. 1, measured when the most protected crop (Bt, S1) was ready for picking.

Treatment[A]	**Yield (% of most protected crop)**
Bt, S1	100 (10.7 b/ha)
Bt, S2	76
Conventional, S1	86
Conventional, S2	57

[A] Results are averaged across variety backgrounds (Sicala V2, Siokra V15) which responded similarly to treatments; see Table 1 for details of treatments.

Table 3. Comparative tolerance to tipping out and fruit loss of Bt and conventional cotton. The ratio between the yield of manually damaged crops and that of undisturbed controls is taken as an approximate measure of tolerance.

Cotton	Damage[a]	Yield ratio	Source
Bt	V	0.86	Exp. 2, this study
Bt	V	1-1.3	Wilson & Sadras (unpublished)
Conv.	V	0.72 to 1.06	Bishop et al. (1977)
Conv.	V	1.0 to 1.10	Brook et al. (1992b)
Conv.	V	0.96 to 0.98	Evenson (1969)
Conv.	V	0.92 to 1.29	Sadras (1996c)
Bt	R	0.81 to 0.94	Exp. 2, this study
Bt	R	0.86 to 1.11	Exp. 3, this study
Conv.	R	0.59 to 1.12	Brook et al. (1992b)
Conv.	R	0.80 to 1.03	Evenson (1969)
Conv.	R	0.20 to 1.24	Kennedy et al. (1986)
Conv.	R	0.64 to 1.12	Kincade et al. (1970)
Conv.	R	0.99 to 1.27	Kletter and Wallach (1982)
Conv.	R	0.97 to 1.03	Pettigrew et al. (1992)
Conv.	R	0.81 to 0.92	Sadras (1996a)
Conv.	R	0.56 to 1.13	Ungar et al. (1987)
Conv.	R	0.82 to 1.21	Wilson and Bishop (1982)
Bt	V + R	0.76	Exp. 2, this study
Conv.	V + R	0.97 to 1.05	Brook et al. (1992b)

[a]V: tipped out, R: removal of squares and/or bolls