known from Alaska, where potholes up to 6 m in diameter and 5 m in depth were formed in sandstone in 85 years[4]. Bloom[5] has reported about four times increase in the pothole dimensions developed into shale and siltstones between 1963 and 1983, in the Coy Glen, New York. It is most important to note that these rapidly formed potholes were developed in relatively less resistant substrate. In the Indian subcontinent, although a few attempts have been made to estimate or measure the rates of bedrock erosion on the Indus river on the basis of cosmogenic dating and by using drill holes in rocks[6–8], there are no reports on quantitative estimates for rates of pothole erosion. Therefore, the results of this study are significant because the evidence shows that discernable bedrock erosion can take place on human timescale.

The findings of the present study have implications for improving our understanding of the less-studied bedrock river channels in India, which are dominated by amazingly high levels of power expenditure during monsoon floods[9,10], but are generally assumed to be more stable and less dynamic than the alluvial river channels[9].

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Impact of insecticides on sucking pests and natural enemy complex of transgenic cotton

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Development of transgenic cotton appears to be effective in managing the bollworm population. However, selection of suitable techniques to manage the sucking pest population on transgenic cotton is needed. Studies were made to assess the impact of insecticides on sucking pests and natural enemy complex on transgenic cotton. Results of field studies conducted during kharif 2002 at the Department of Cotton, Tamil Nadu Agricultural University, Coimbatore under irrigated conditions revealed that seed treatment of transgenic cotton with imidacloprid @ 5 g kg^{-1} of seeds was more effective than other treatments in keeping the populations of leafhoppers, *Amrasca devastans* (Dist.); aphids, *Aphis gossypii* (Glover); thrips, *Scirtothrips dorsalis* (Hood) and whitefly, *Bemisia tabaci* (Gennadius) below economic threshold level up to 40 days after sowing. The studies also showed that seed treatment of transgenic cotton with imidacloprid was not only safe but also attracted predators, viz. coccinellid beetles, *Coccinella septumpunctata* (Linnaeus) and *Cheilomenes sexmaculatus* (Fabricius); green lace wing, *Chrysoperla carnea* (Stephens) and Lynx spider, *Oxyopes javanus* (Thorell); orb spider, *Argiope minuta* (Karsh); wolf spider, *Lycosa pseudoannulata* (Boesenberg and Strand); long-javed spider, *Tetragnatha javana* (Thorell); *Neoscona theisi* (Walcknear) and *Peucetia viridana* (Stoliczka) in transgenic cotton.

COTTON, *Gossypium hirsutum* L., an important industrial crop of the world, is grown in an area of more than 38 million hectares (m ha), of which approximately 24% is in India. Punjab, Haryana, Rajasthan, Maharashtra, Gujarat, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu are the major cotton-growing states of India. India is the third largest global cotton producer. Despite the large area (9.2 m ha), productivity is far below (290 kg/ha) the global average and production is only 19.6 million bales[1,2]. The low yields (up to 35–40%) are mainly attributable to insect pests.

About 162 species of insects occur in cotton at various stages of growth, of which 15 are key pests. Sap feeders, viz. leafhopper, *Amrasca devastans* (Dist.); aphid, *Aphis gossypii* (Glover); thrips, *Scirtothrips dorsalis* (Hood) and whitefly, *Bemisia tabaci* (Gennadius) damage the cotton crop with regular occurrence at different growth stages,

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reducing the growth and yield. Transgenic cotton is promising in the management of bollworm population only[3,4]. Hence, suitable techniques to manage the sucking pest population on transgenic cotton are needed. Imidacloprid as a seed-dresser insecticide is effective against sucking pests of cotton[5]. The present study was made to assess the effects of insecticides treatments on transgenic cotton.

The effect of insecticides on sucking pests and their natural enemies in transgenic cotton and non-transgenic cotton was studied in a field experiment during kharif 2002 at the Department of Cotton, Tamil Nadu Agricultural University, Coimbatore under irrigated conditions. The experiment was conducted in a randomized block design (RBD) with nine treatments and three replications. The treatments included are given in Table 1.

Observations on the population of sucking pests, viz. leafhopper, *A. devastans* (Dist.); aphid, *A. gossypii* (Glover); thrips, *S. dorsalis* (Hood) and whiteflies, *B. tabaci* (Gennadius) were recorded at fortnightly intervals up to 70 days on three leaves (top, middle and bottom canopy of the plants) per plant by randomly selecting five plants from each plot. Similarly, observations on the population of natural enemies, viz. predatory coccinellid beetles, *Coccinella septumpunctata* (Linnaeus) and *Cheilomenes sexmaculatus* (Fabricius); green lace wing, *Chrysoperla carnea* (Stephens); and spiders such as lynx spider, *Oxyopes javanus* (Thorell); orb spider, *Argiope minuta* (Karsh); wolf spider, *Lycosa pseudoannulata* (Boesenberg and Strand); long-javed spider, *Tetragnatha javana* (Thorell); *Neoscona theisi* (Walcknear) and *Peucetia viridana* (Stoliczka) were recorded. The data on mean population of sucking pests and their natural enemies were subjected to statistical analyses (ANOVA and DMRT).

There was higher incidence of leafhoppers and thrips, moderate incidence of aphids and low incidence of whiteflies during 2002 kharif season. The effects of insecticides on sucking pests and their natural enemies, on both transgenic and non-transgenic cotton, are presented in Figure 1 *a–g*. Data on the effect of different treatments on the population of leafhopper, *A. devastans* showed significant differences at different intervals of observations (Figure 1 *a*). Among the treatments, imidacloprid seed treatment was found to be significantly superior in reducing leafhopper infestation compared to the other treatments. The lowest leafhopper populations (0.00, 1.03, 2.55 and 2.53 hoppers per leaf) were observed on transgenic cotton with imidacloprid seed treatment at different intervals. The highest leafhopper populations were observed on TCHB 213 without any treatments, recording 2.1, 3.15, 3.8 and 4.51 hoppers per leaf on 3, 5, 7 and 9 weeks after sowing, respectively.

Table 1. Treatments included in the study

Treatment number	Cultivar	Chemical	Concentration
T1	Bt MECH 162		
T2	MECH 162	Imidacloprid	5 g*
T3	TCHB 213		
T4	Bt MECH 162		
T5	MECH 162	Dimethoate	500 ml**
T6	TCHB 213		
T7	Bt MECH 162		
T8	MECH 162	No spray	–
T9	TCHB 213		

*Imidacloprid @ 5 g/kg of seed (seed treatment).
**Dimethoate @ 500 ml/ha; sprayed when the pest population crossed the economic threshold level.

Similarly, the lowest thrips populations, viz. 0.003, 1.83, 2.77 and 0.83 thrips per leaf were observed on transgenic cotton with imidacloprid treatment at different intervals (Figure 1 *b*). A similar trend was also noticed with aphids and whitefly populations. A lowest population of 3.10 aphids per leaf and 0.45 whiteflies per leaf was observed on 63 days after sowing (Figure 1 *c* and *d*) on transgenic cotton with imidacloprid seed treatment.

Observations on the natural enemies revealed that the populations of *C. septumpunctata*, *C. sexmaculatus* and spiders were significantly higher in plots treated with imidacloprid than untreated plots. Maximum number of 2.4 coccinellid adults per plant on 63 days after sowing was observed in transgenic cotton with imidacloprid seed treatment, whereas it was only 0.86 beetles per plant in plots sprayed with dimethoate (Figure 1 *e*). In case of *C. carnea* eggs, the plots which received imidacloprid seed treatment had significantly higher egg populations than the untreated check. Highest number of eggs was observed on transgenic cotton with imidacloprid seed treatment (0.6 eggs per plant, 63 days after sowing; Figure 1 *f*). However, dimethoate spraying reduced *C. carnea* egg laying and it was on par with the untreated check.

In the case of spiders, *O. javanus*, *A. minuta*, *L. pseudoannulata*, *N. theisi and P. viridana*, imidacloprid seed treatment had recorded higher populatons than the untreated check. Among the treatments, highest number of spiders (0.2, 1.2, 1.6 and 1 per plant) was recorded on transgenic cotton treated with imidacloprid. Lowest number of spiders (0.07, 0.0, 0.2 and 0.2 per plant) was observed on TCHB 213, sprayed with dimethoate (Figure 1 *g*).

The present findings agree with the results reported by Mote *et al.*[6] and Patil *et al.*[7], who concluded that seed treatment with imidacloprid reduced the sucking pest population below the economic threshold level up to 40 days after sowing. Seed treatment of cotton with imidacloprid was effective against leafhopper population up to 61 days after germination[2,3]. Whereas spraying of imidacloprid on cotton against leafhopper was less effective[8]. Salmon[9] reported that imidacloprid seed treatment showed impressive biological efficacy against sucking pests of cotton under African conditions. However, imidacloprid seed treatment was less effective in controlling thrips, which is not in agreement with the present findings[10]. Thus, the new seed dresser is found to offer better protection against early-season sucking pests on transgenic cotton.

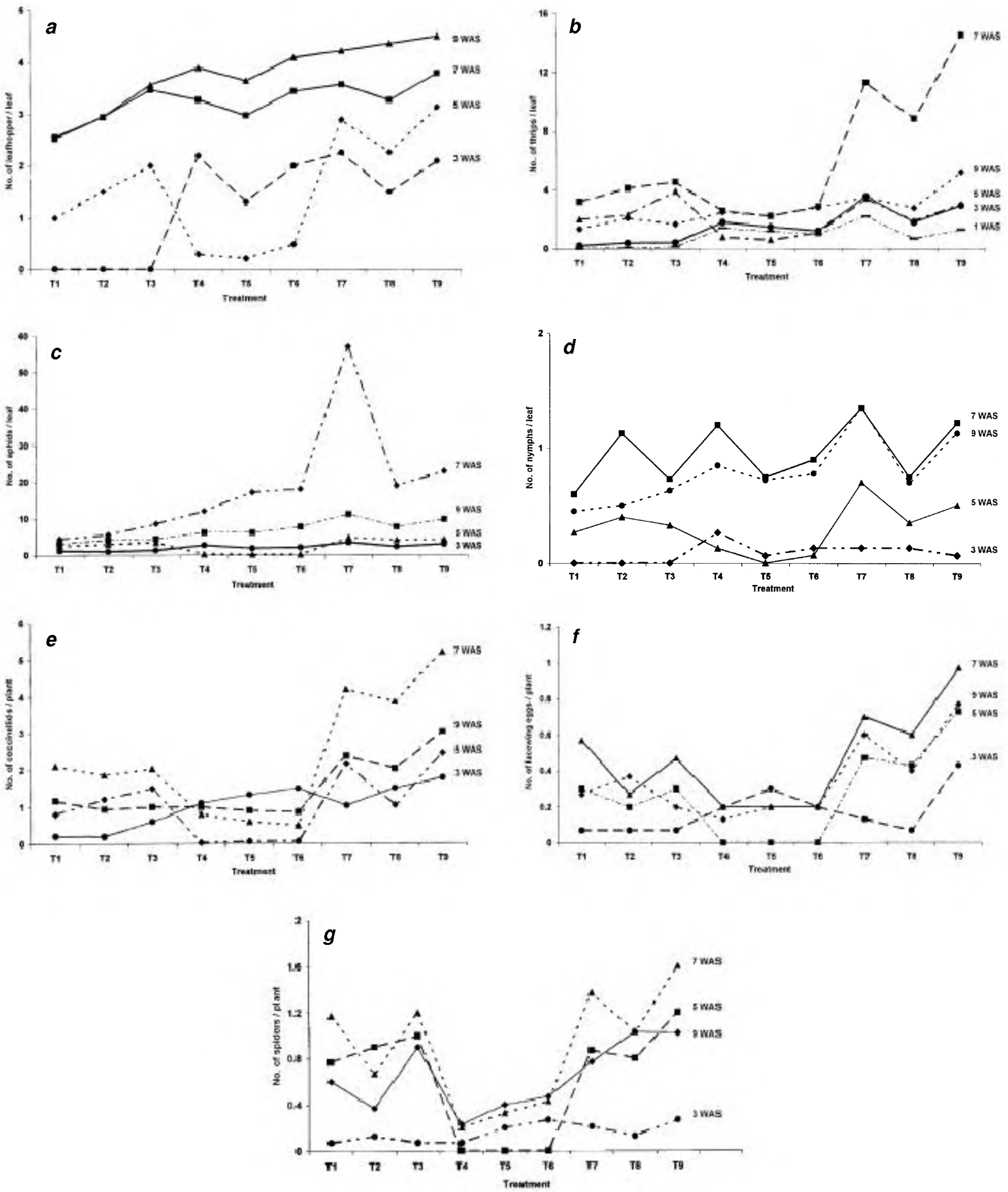

Figure 1. Effect of insecticides on (*a*) leafhopper, (*b*) thrips, (*c*) aphid, (*d*) whitefly, (*e*) coccinellids, (*f*) *Chrysoperla carnea* and (*g*) spiders on transgenic cotton. WAS, Weeks after sowing.

The results indicated that seed treatment of transgenic cotton with imidacloprid was not only safer but also attracted predators to the plants. It is further revealed that *C. sexmaculatus*, *C. septumpunctata*, *C. carnea* and spiders preferred plants raised from seed treated with imidacloprid than the control. Imidacloprid seed treatment increased the nitrogen and chlorophyll content in cotton plants[6]. Imidacloprid molecules contain five nitrogen atoms each, the major elements required for plant growth. Higher nitrogen and chlorophyll content in cotton plants, besides avoiding direct contact of seed dressers with predators, may probably be the reason for seed treatment being safer, consolative and attractive to these insect predators. These results are consistent with those of earlier studies by Satpute *et al.*[11], who concluded that imidacloprid seed treatment was attractive to the coccinellids, *Chrysopa* predators in cotton under higher doses. Further, studies also indicated that seed treatment was safer than foliar sprays against ladybird beetles and egg laying by *C. carnea* on cotton ecosystem[12].

Imidacloprid is physiologically active against a wide range of insects, including some beneficial species. It was topically toxic to predatory arthropods, aphelinid parasitoid, *Aphidius ervi* (Haliday), adults and larvae of the coccinellids, *Hippodamia convergens* (Guerin–Menerille) and the bees, *Apis mellifera* L., *Nomia melanderi* (Cockerell), and *Megachile rotundata* (F.) in laboratory conditions. It was also toxic to a predatory pentatomid bug, *Podisus maculiventris* (Say), when exposure occurred topically, by residual contact or from ingestion[13]. On the contrary, imidacloprid was less toxic to the predator *C. carnea* and parasitoid such as *Eretmocerus mundus* (Mercet), a pupal parasitoid of *Bemisia tabaci* and *Trichogramma japonicum* (Ashmead), an egg parasitoid of lepidopterous pest[14], when used as spray. Further studies showed that granular imidacloprid caused some short-term suppression of earthworms up to 40 days and reduced pitfall capture of predatory coleopterans; but greater abundance of ants, carabids, spiders and Staphylinids was observed; thus laboratory toxicity tests may not always reflect a pesticide impact on non-target invertebrates in the field[15]. The present investigation suggests that the new seed dresser offers promising protection against sucking pest of transgenic cotton and increased activity of natural enemies which suppressed subsequent resurgence and secondary pest outbreak. Thus, seed treatment of transgenic cotton with midacloprid can be an ideal strategy for integrated pest management in transgenic cotton.

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