

Laboratory and field studies on the integrated pest management of *Helicoverpa armigera* (Hübner) in cotton, based on pheromone trap catch threshold level

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Abstract: With a view to using parasitoids and predators in integrated pest management of the target pest *Helicoverpa armigera* in cotton fields, basic studies on the egg parasitism, toxicity of insecticides to parasitoids and predators and compatibility of nuclear polyhedrosis virus (NPV) of *H. armigera* with other insecticides were conducted in the laboratory. Results revealed that egg parasitism in the laboratory by *Trichogramma chilonis* was 75.6%. Among the insecticides tested against *T. chilonis* and the predator *Chrysoperla carnea*, nimbecidine (neem product) and dipel resulted in zero mortality, with only a low level of mortality by dimethoate, cypermethrin, fenvalerate, alphamethrin and monocrotophos. Combinations of nimbecidine 2% + NPV at 250 larval equivalents (LE)/ha and dipel 81 + NPV @250 LE/ha were the most effective treatments against *H. armigera*. The integrated pest management components (*T. chilonis*, *C. carnea*, NPV, nimbecidine, dipel and synthetic chemicals) were imposed at different intervals on the basis of pheromone trap threshold level (7 moths/trap per night) on a consolidated block of 40 ha cotton (MCU-1) fields at two locations, Shankarabanda and Korlagundi. The results demonstrated a significant superiority of the IPM strategy in terms of both cost versus benefit and environmental safety over that used in the farmer's fields where only conventional control methods were followed.

1 Introduction

The American bollworm or gram pod borer, *Helicoverpa armigera* (Hübner) (Lep., Noctuidae), is one of the major pests of cotton in almost all of the cotton growing areas of the world, causing both quantitative and qualitative losses. Due to the high cost of protecting crops from *H. armigera* with chemical pesticides (SUNDARAMURTHY, 1986; ANONYMOUS, 1990) and the increasing resistance and resurgence to many chemical pesticides (UTHAMASAMY, 1990; ARMES et al., 1992) there is growing interest in the use of pheromones, natural enemies (predators and parasitoids) and other novel methods for controlling such pests.

During the last two decades, considerable work has been carried out on the use of pheromones (ROTHSCHILD et al., 1982; KEHAT and DUNKELBLUM, 1993; CHEN et al., 1995), parasitoids (NAGARKATTI, 1982), predators (GREATHEAD and GIRLING, 1982; KING et al., 1982), microbial insecticides including nuclear polyhedrosis virus (NPV) (TINSLEY, 1979; BELL, 1982; MCKINLEY, 1982), neem extracts (THAKUR et al., 1988; RAO et al., 1990) including its application technology, safety testing, and the use of these techniques in pest management. However, an important factor in the search for alternatives was that no single method of control can be expected to provide an acceptable solution to all insect problems where a complex of pests is involved. The discipline of integrated pest management (IPM) has been built on the

philosophy of total system consideration and multiple control techniques.

This paper is not intended to demonstrate novel methods for the control of *H. armigera*. Rather, it is an attempt to evaluate how the available IPM control methods could be best used practically to control this pest in cotton. The IPM emphasis is on environmentally friendly inputs, with chemical pesticides only being used when pest numbers exceed predetermined thresholds.

2 Materials and methods

2.1 Egg parasitism of *H. armigera* under laboratory condition

Host acceptance was observed by collecting 100 *H. armigera* eggs from cotton fields. These were exposed to *Trichogramma chilonis* for parasitism determination in the laboratory. Twenty adult female parasitoids (12–24 h after emergence) were released in cages (15 cm × 15 cm × 15 cm). Eggs of *H. armigera* on paper glued to the upper surface of cotton leaves were exposed for one night. This treatment was replicated four times. The parasitized eggs were counted and percentage parasitism was calculated. The tests were conducted in the laboratory in a 14 h light : 10 h dark photoperiod at 30 ± 2°C and 50–60% relative humidity.

Table 1. Effect of insecticides on the egg parasitoid *Trichogramma chilonis* in the laboratory

Insecticide	Concentration (%) v/v	No. of parasitoids exposed	Mean percentage mortality after		
			6 h	24 h	48 h
Endosulfan 35 EC	0.070	25	82.2 (65.4)	100.0 (90.0)	100.0 (90.0)
Phosalone 25 EC	2.000	25	10.6 (19.0)	52.33 (46.0)	82.3 (66.4)
Methomyl 25 EC	0.025	25	86.6 (67.4)	100.0 (90.0)	100.0 (90.0)
Alphamethrin 10 EC	0.010	25	00.0 (00.0)	1.9 (4.5)	3.3 (7.8)
Cypermethrin 20 EC	0.020	25	00.0 (00.0)	1.8 (4.3)	2.1 (6.8)
Fenvalerate 20 EC	0.010	25	00.0 (00.0)	1.2 (3.6)	2.8 (7.4)
Monocrotophos 36 SL	0.035	25	00.0 (00.0)	2.6 (7.6)	3.2 (8.8)
Dimethoate 30 EC	0.050	25	00.0 (00.0)	1.2 (3.8)	1.7 (3.9)
Nimbecidine	2.500	25	00.0 (00.0)	00.0 (00.0)	00.0 (00.0)
Dipel 8L	2.000	25	00.0 (00.0)	00.0 (00.0)	00.0 (00.0)
Quinalphos 25 EC	1.500	25	96.7 (86.1)	100.0 (90.0)	100.0 (90.0)
Tap Water	–	25	00.0 (00.0)	00.0 (00.0)	00.0 (00.0)
SEM	–	–	2.324	3.421	2.021
CD at 5%	–	–	8.758	8.266	6.458

Values in the parentheses indicate means of angular transformed values.

2.2 Effect of insecticides on natural enemies

2.2.1 Toxicity of available insecticides to egg parasitoid, *T. chilonis*

In order to test the effect of various insecticides on *T. chilonis*, 36 cards (4 cm × 2 cm) were prepared each with 100 fresh-laid *H. armigera* eggs glued to it. Each card was exposed to 25 *T. chilonis* adult female parasitoids in a glass tube (10 cm × 2.5 cm) for 24 h. These cards, with the parasitoid in the egg stage inside *H. armigera* eggs, were treated with 11 different insecticides as shown in table 1, and tap water (control). Observations on mortality of the parasitoids from different treatments were recorded. Each treatment was replicated three times. The tests were conducted in the laboratory in a 14 h light : 10 h dark photoperiod at 30 ± 2°C and 50–60% relative humidity.

2.3 Toxicity of insecticides to *Chrysoperla carnea*

Tests of toxicity of selected insecticides on *C. carnea* were initiated at different concentrations by dipping the first instar larvae of *H. armigera*. For these studies, three replicates of 100 first instar larvae of *H. armigera* were dipped in different concentrations of selected insecticides as shown in table 2, for 5 min and fed to 25 adult bugs of *C. carnea* in a small cage (20 cm × 20 cm). The treated *H. armigera* larvae were fed to each group once in 2 days until pupation and finally the adult mortality of *C. carnea* was recorded. The tests were carried out in the laboratory in a 14 h light : 10 h dark photoperiod at 30 ± 2°C and 50–60% relative humidity.

2.4 Efficacy of *H. armigera* NPV with chemical insecticides

The combined efficacy of *H. armigera* NPV with different insecticides was evaluated on *H. armigera*. For these studies, pieces of cotton leaves (5 cm × 5 cm) were dipped in different concentrations as shown in table 3, for 5 min and air-dried. Three replications of 10 first instar larvae each were used. Three treated leaf pieces were fed to each group once in 2 days until pupation and the mortality was recorded.

The tests were conducted in the laboratory in a 14 h light : 10 h dark photoperiod at 30 ± 2°C and 50–60% relative humidity.

2.5 Pheromone trap catches as management tool for *H. armigera* of cotton

The experiments were conducted at two locations, Sankarabanda and Korlagundi, in upland areas in the state of Karnataka, India during 1993–94 on a consolidated block of 40 ha of cotton at each location. The cotton variety MCU-5 (*Gossypium hirsutum*) was sown and cultivated with recommended agronomic practices (ANONYMOUS, 1992).

Pheromone-baited funnel traps (obtained from Pest Control (India) Ltd, Bangalore), were installed at the rate of 10 traps/ha at 49 days after sowing (d.a.s.). The septa containing (Z)-11-hexadecenal-1-ol and (E)-11-hexadecenal were changed every 4 weeks (PAWAR et al., 1988). The traps were placed just above the crop canopy (30 cm high). Trap height was adjusted according to the crop growth in the field. Dichlorovos (Nuvan 100 EC) at 0.2% was used as a fumigant in the traps to kill the trapped moths. The number of male moths captured in traps were counted and removed daily. The treatments as shown in tables 4 and 5 were imposed within 24 h after the moth captures exceeded 7 moths/trap per night, as this been suggested as the trap catch economic threshold level for *H. armigera* in cotton (PRASAD et al., 1993). The different treatments imposed when the threshold was exceeded and application day for each treatment at both locations in IPM plots are given in tables 4 and 5. On the basis of the pheromone trap catches in IPM plots, the release of *T. chilonis* (250 000/ha) was made at 56 d.a.s. and followed by a second release of *T. chilonis* + *C. carnea* (2500 egg/ha) at 63 d.a.s. and another release of *T. chilonis* + *C. carnea* at 70 d.a.s. This was followed by NPV [250 larval equivalents (LE)/ha] at 84 d.a.s., monocrotophos (2.8 l/ha) at 91 d.a.s., cypermethrin (0.56 l/ha) at 98 d.a.s., alphamethrin (0.56 l/ha) at 105 d.a.s., NPV + nimbecidine (625 ml/ha) at 112 d.a.s. and the same treatment was repeated again at 119 d.a.s.; a subsequent treatment with dipel WP (500 gm/ha) + nimbecidine (625 ml/ha) was carried out at 145 d.a.s. at Shankarabanda and the

Table 2. Effect of insecticides on the predator *Chrysoperla carnea* in the laboratory

Insecticide	Concentration (%) v/v	No. of adult bugs tested	Mean percentage mortality after		
			6 h	24 h	48 h
Endosulfan 35 EC	0.070	25	84.4 (66.2)	100.0 (90.0)	100.0 (90.0)
Phosalone 25 EC	2.000	25	54.2 (48.2)	86.4 (64.3)	100.0 (90.0)
Methomyl 25 EC	0.025	25	92.0 (82.2)	100.0 (90.0)	100.0 (90.0)
Alphamethrin 10 EC	0.010	25	1.4 (3.2)	2.5 (6.5)	4.2 (8.7)
Cypermethrin 20 EC	0.020	25	1.2 (3.8)	2.2 (3.8)	8.3 (24.2)
Fenvalerate 20 EC	0.010	25	00.0 (00.0)	1.2 (3.4)	4.8 (12.3)
Monocrotophos 36 SL	0.035	25	00.0 (00.0)	00.0 (0.0)	2.8 (7.4)
Dimethoate 30 EC	0.050	25	00.0 (00.0)	1.2 (3.8)	15.2 (46.2)
Nimbecidine	2.500	25	00.0 (00.0)	00.0 (00.0)	00.0 (00.0)
Dipel 8L	2.000	25	00.0 (00.0)	00.0 (00.0)	00.0 (00.0)
Quinalphos 25 EC	1.500	25	98.0 (82.7)	100.0 (90.0)	100.0 (90.0)
Tap Water	–	25	00.0 (00.0)	00.0 (00.0)	00.0 (00.0)
SEM	–	–	2.480	2.604	3.020
CD at 5%	–	–	8.082	8.270	6.421

Values in the parentheses indicate means of angular transformed values.

same treatment was carried out at 138 d.a.s. at the Korlagundi location.

Similarly, a consolidated block of 40 ha of the farmers' fields at both locations was chosen as control plots. The farmers at both the locations sowed and cultivated MCU-5 with the same recommended agronomic practices (ANONYMOUS, 1992), but the insecticidal sprays were carried out at their own discretion (table 6). The distance between the IPM and farmers' plots at each location was about 0.5 km and the distance between the two locations was 20 km.

2.6 Spray applications

All the insecticidal applications in IPM and farmers' plots were made using a lever-operated knapsack sprayer with hollow cone jet operated at 3 bar pressure. The quantity of spray fluid was used at 750 l/ha in IPM plots at both locations and also in the farmers' field at Shankarabanda, but 800 l/ha of spray fluid was used by the farmers at Korlagundi. A liquid formulation of NPV was applied at a rate of 250 LE/ha using a battery-operated spinning disc sprayer. The NPV suspensions were applied in water with 20% jaggery and 5% 'Robin Blue' as an adjuvant. All applications in IPM took place between 1600 and 1830 h and in farmers' fields between 0700 and 1000 h and between 1600 and 1830 h.

2.7 Square damage and yield assessment

The percentage of square damage was assessed by counting the mean number of holes produced in 100 plants, which had been selected at random per plot in the IPM and at two test locations in the farmers' plots were recorded at weekly intervals.

The observations on yield were taken randomly from an area of (0.4 ha) at each of five locations, in each experimental plot and from each of the farmer's fields (0.4 ha from each) where conventional practices were used. The relative cost benefits were calculated for both the IPM and farmer practices at both locations.

2.8 Statistical analysis

For statistical analysis of toxicity of insecticides to parasitoids and predators and compatibility of *H. armigera* NPV with other insecticides, the data were angular-transformed (arcsine transformation) and mortality due to the different insecticides were analysed using an *F*-test. For the field trials the percentage of square damage, egg parasitoid and yield of seed cotton (t/ha) for each location were analysed using GENSTAT (version 4.04, SAS Institute Inc, SAS/STAT) analysis of variance.

3 Results

3.1 Egg parasitism of *H. armigera* under laboratory conditions

Egg parasitism of *H. armigera* by *T. chilonis* has showed that the average percentage parasitism was 75.6. This indicated that the parasitoid *T. chilonis* was acceptable to *H. armigera* eggs, which were collected from the field.

3.2 Effect of insecticides on natural enemies

3.2.1 Toxicity of insecticides to *T. chilonis*

Parasitoid mortality ranged from 0 to 96.7% and 0–100%, at 6 and 24 h, respectively, after insecticide treatment. Quinalphos recorded 96.7% mortality and was significantly more toxic than the rest of the treatments. Endosulfan and methomyl caused 82.2 and 86.7% mortality and were significantly more toxic than eight other treatments at this time. Endosulfan, methomyl and quinalphos were highly toxic and caused nearly 100% adult mortality and differed significantly from the rest of the treatments at 24 h. Nimbecidine, dipel, fenvalerate, dimethoate, monocrotophos, alphamethrin and cypermethrin caused only little or no mortality (0–2.6%) at 24 h treatment (table 1).

Among all the insecticides tested nimbecidine, alphamethrin, monocrotophos, dimethoate and dipel were the safest insecticide and caused no mortality at 6 h exposure. This was followed by dimethoate, cypermethrin, fenvalerate and monocrotophos which caused 1.75, 2.10, 2.86 and 3.22% mortality, respectively. Insecticides arranged in order from least to most toxic were nimbecidine, dipel, dimethoate, cypermethrin, fenvalerate, monocrotophos, alphamethrin, phosalone, endosulfan, methomyl and quinalphos at 48 h after treatment.

3.2.2 Toxicity of insecticides to the predator *C. carnea*

Table 2 shows the contact toxicity of test compounds at recommended field doses. Mortality of adult *C. carnea* ranged from zero to 98%, after 6 h of treatment. Quinalphos recorded the maximum percentage mortality (98%) followed by methomyl and endosulfan and these three were significantly more toxic than phosalone which caused 54.22% adult mortality, after 6 h treatment. The results for nimbecidine, dipel, dimethoate, fenvalerate and monocrotophos treatments was 0% mortality. The mortality was high in quinalphos, methomyl and endosulfan treatments after 24 h. The percentage mortality was 2.2, 1.2, 1.3 in cypermethrin, fenvalerate and dimethoate treatments, respectively. Nimbecidine, dipel and monocrotophos treatments resulted in 0% mortality (table 2).

At 48 h after treatment, endosulfan, phosalone, methomyl and quinalphos caused 100.0% mortality of the test population. The treatments differed significantly from the dimethoate, cypermethrin, fenvalerate and monocrotophos treatments which recorded 15.22, 8.32, 4.86 and 2.82% mortality. Nimbecidine, dipel and tap water caused 0.0% mortality and were found to be the safest among the insecticides tested.

3.2.3 Efficacy of *H. armigera* NPV with chemical insecticides

When NPV or combinations with chemical insecticides were tested against the larvae of *H. armigera*, the mortality ranged from 54 to 94.3% (table 3). The highest larval mortality was recorded in nimbecidine 2% + NPV at 250 LE/ha (94.3%) followed by dipel 8 l 2% + NPV at 250 LE/ha (84.0%) and, alphamethrin 10 EC 0.01% + NPV at 250 LE/ha (82.3%). Application of NPV at 500 LE/ha, NPV at 250 LE/ha, monocrotophos 0.018% + NPV at 250 LE/ha, cypermethrin 0.02% + NPV at 250 LE/ha and fenvalerate 0.015% + NPV at 250 LE/ha were about equally toxic, providing 71.0–79.7% larval mortality. In the second experiment, larval mortality ranged from 63.0 to 93.0%, with greatest larval mortality in the nimbecidine + NPV treatment, followed closely by the dipel WP + NPV (88.0%) and dipel 8 l + NPV (85.0%) treatments.

The pooled data shows that nimbecidine + NPV, dipel WP + NPV and dipel 8 l + NPV treatments were more effective than the rest of the treatments, providing 93.7, 87.0 and 84.5% mortality, respectively. Alphamethrin + NPV (82.6% mortality) and monocrotophos + NPV (80.3%) were somewhat less effective. The combination of carbaryl WP + NPV was found to be less effective (58.5% mortality) than the application of NPV alone.

3.3 Pheromone trap catches as management tools for *H. armigera* of cotton

Fifty-six days after planting and 7 days after the pheromone traps were installed, observations revealed that there was 31.3% square damage at Sankarabanda (table 4), and at Korlagundi location there was 33.3% square damage (table 5). At this time the first release of parasitoid *T. chilonis* was made. After the second release of *T. chilonis* and *C. carnea* at 63 d.a.s., the

Table 3. Combined efficacy of NPV and insecticide application against larvae of *Helicoverpa armigera* in the laboratory

	Mean percentage mortality		Treatments Pooled
	First experiment	Second experiment	
Untreated check	—	—	—
NPV at 500 LE/ha	72.6 (59.0)	73.6 (59.2)	73.1(59.1)
NPV at 250 LE/ha	71.0 (57.4)	70.0 (56.3)	70.5 (56.8)
Nimbecidine 2% + NPV at 250 LE/ha	94.3 (75.0)	93.0 (73.5)	93.6 (74.2)
Monocrotophos 36 SL 0.018% + NPV at 250 LE/ha	78.6 (62.2)	82.0 (65.3)	80.3 (63.7)
Cypermethrin 20 EC 0.02% + NPV at 250 LE/ha	76.6 (61.0)	76.8 (61.3)	76.7 (61.1)
Alphamethrin 10 EC 0.01% + NPV at 250 LE/ha	82.3 (65.1)	83.0 (65.2)	82.6 (65.1)
Dipel 8L 2% + NPV at 250 LE/ha	84.0 (66.4)	85.0 (67.2)	84.5 (66.8)
Dipel WP 2% + NPV at 250 LE/ha	86.0 (67.4)	88.0 (70.6)	87.0 (69.0)
Carbaryl 50 WP 0.2% + NPV at 250 LE/ha	54.0 (47.2)	63.0 (52.5)	58.5 (49.9)
Fenvalerate 20 EC 0.015% + NPV @250 LE/ha	79.7 (63.1)	80.2 (63.6)	79.9 (63.4)
SEM	1.83	2.31	2.02
CD @5%	4.27	6.04	6.23

Values within parenthesis are angular transformed values.

trap catches were above the economic threshold level at both locations. When the treatment with NPV (250 LE/ha) was made on the cotton fields, the trap catches at both locations were still higher than the threshold level. The percentage of egg parasitism steadily increased from zero to a maximum of 45% at Shankarabanda and 52.0% at Korlagundi. The mean trap catches was drastically reduced to 30% at Shankarabanda and 20% after spraying monocrotophos at 91 d.a.s., cypermethrin (0.56 l/ha) at 98 d.a.s. and alphamethrin (0.56 l/ha) at 105 d.a.s. Surprisingly, egg parasitism was reduced to 12 and 21% at Shankarabanda and Korlagundi, respectively. However, the mean trap catches fell below the economic threshold level at Shankarabanda (5.0 moths/trap per night) and at Korlagundi (6.0 moths/trap per night) at 159 d.a.s. after imposing the treatments NPV + nimbecidine at 112 and 119 d.a.s, dipel 81 (500 ml/ha) + nimbecidine (625 ml/ha) at 126 d.a.s and dipel WP (500 gm/ha) + nimbecidine at 145 d.a.s. at Shankarabanda and at 138 d.a.s. at Korlagundi.

Although insecticidal spraying was carried out almost every week from 49 to 194 d.a.s. in the farmers' fields at both locations (table 6), the percentage of square damage was only reduced from 32 to 14% and 38.5 to 17.0% at Shankarabanda and Korlagundi, respectively. The percentage of natural egg

parasitism recorded was very low (2%) at both the locations. The average wind velocity and temperature prevailing during the season were 4.80 m/s and 34.5°C in Shankarabanda and 4.26 m/s and 35.0°C in Korlagundi.

3.4 Yield

The average yield from IPM plots indicated a mean of 2.26 t/ha compared with 1.58 t/ha in the farmers' plots which is an increase of 0.71 t/ha in Shankarabanda and 0.65 t/ha in Korlagundi; an average of 0.68 t/ha (table 7).

3.5 Economic analysis of investment versus benefit

The economic analysis of the cost incurred in IPM plots compared with that of farmers' fields indicated an average of Rs 2728.70/ha was spent in IPM plots and an average of Rs 6997.50/ha on the farmers' plots. Conversely, the higher amount was equivalent to a savings of Rs 3634.70/ha on the amount invested and an average net return of Rs 8900.60 obtained from the gross income thereby implying obvious advantages of IPM over the conventional insecticides in the cotton ecosystem (table 7).

Table 4. Effect of different treatments against *H. armigera* at Shankarabanda

Crop stage (DAS)	Mean trap catches in IPM plots	Different treatments imposed in IPM plots	IPM plots		Farmers' plots ¹	
			% square damage	% egg parasitism	% square damage	% egg parasitism
49	–	Traps installed (10 traps/ha)	34.0	0.0	32.0	0.0
56	263.0	<i>Trichogramma</i> (250 000/ha)	31.3	0.0	33.5	1.0
63	234.0	<i>Trichogramma</i> (250 000/ha) + <i>Chrysoperla</i> (2500 egg/ha)	29.2	17.2	30.0	0.5
70	170.0	<i>Trichogramma</i> (250 000/ha) + <i>Chrysoperla</i> (2500 egg/ha)	26.8	19.2	30.0	0.0
77	171.0	–	24.5	39.0	28.0	1.0
84	136.0	NPV (250 LE/ha)	24.2	42.0	27.5	1.0
91	106.0	Monocrotophos (2.8 l/ha)	23.5	45.0	26.0	2.0
98	67.0	Cypermethrin (0.56 l/ha)	23.3	12.0	24.5	2.0
105	43.0	Alphamethrin (0.56 l/ha)	21.0	9.0	24.0	0.0
112	38.0	NPV + Nimbecidine (625 ml/ha)	18.8	6.0	23.0	0.0
119	26.0	NPV + Nimbecidine (625 ml/ha)	18.2	4.0	22.5	1.0
126	21.5	Dipel 8 L (500 ml/ha) + Nimbecidine (625 ml/ha)	17.0	2.0	22.0	2.0
131	21.0	–	15.5	1.0	21.0	1.0
138	17.0	–	15.2	0.0	20.0	0.0
145	14.0	Dipel WP (500 gm/ha) + Nimbecidine (625 ml/ha)	13.5	1.0	20.0	1.0
152	11.0	–	10.0	1.0	18.5	0.0
159	5.0	–	7.0	0.0	18.0	0.0
166	4.0	–	4.2	1.0	18.0	0.0
173	5.0	–	4.0	0.0	17.0	0.0
180	3.0	–	3.8	2.0	15.0	0.0
187	1.0	–	3.6	0.0	15.0	0.0
194	0.5	–	2.0	0.0	15.0	0.0
201	0.3	–	2.1	0.0	14.5	0.0
208	0.0	–	2.0	0.0	14.0	0.0

DAS, days after sowing.
¹ Details of various insecticidal treatments are shown in table 6.

Table 5. Effect of different treatments against *H. armigera* at Korlagundi

Crop stage (DAS)	Mean trap catches in IPM plots	Different treatments imposed in IPM plots	IPM plots		Farmers' plots ¹	
			% square damage	% egg parasitism	% square damage	% egg parasitism
49	–	Traps installed (10 traps/ha)	37.0	0.0	38.5	2.0
56	214.0	<i>Trichogramma</i> (250 000/ha)	33.3	14.0	38.0	2.0
63	169.0	<i>Trichogramma</i> (250 000/ha) + <i>Chrysoperla</i> (2500 egg/ha)	32.8	34.0	37.0	1.0
70	136.0	<i>Trichogramma</i> (250 000/ha) + <i>Chrysoperla</i> (2500 egg/ha)	31.8	42.0	37.0	2.0
77	118.0	–	30.7	48.0	35.5	2.0
84	102.0	NPV (250 LE/ha)	28.0	48.5	35.0	3.5
91	82.0	Monocrotophos (2.8 l/ha)	26.3	52.0	35.0	2.0
98	48.0	Cypermethrin (0.56 l/ha)	27.0	21.0	33.0	1.0
105	26.5	Alphamethrin (0.56 l/ha)	22.0	14.0	33.0	1.0
112	21.0	NPV + Nimbecidine (625 ml/ha)	21.2	8.0	31.5	0.0
119	18.0	NPV + Nimbecidine (625 ml/ha)	18.8	5.0	31.0	0.0
126	16.0	Dipel 8 L (500 ml/ha) + Nimbecidine (625 ml/ha)	18.5	2.0	30.0	0.0
131	16.5	–	16.0	2.0	25.5	0.0
138	14.0	Dipel WP (500 gm/ha) + Nimbecidine (625 ml/ha)	15.2	1.0	25.5	0.0
145	12.0	–	14.7	0.0	25.0	0.0
152	10.2	–	12.3	0.0	22.5	0.0
159	6.0	–	9.0	0.0	22.0	1.0
166	4.5	–	7.3	0.0	21.0	0.0
173	2.0	–	5.5	1.0	21.5	0.0
180	1.0	–	3.3	1.0	21.0	0.0
187	0.5	–	3.0	0.0	18.0	0.0
194	0.1	–	2.2	0.5	18.0	0.0
201	0.1	–	1.8	0.0	17.5	0.0
208	0.0	–	1.5	0.0	17.0	0.0

DAS, days after sowing.
¹ Details of various insecticidal treatments are shown in table 6.

4 Discussion

According to SPARKS et al. (1982) and PAWAR et al. (1988), *H. armigera* will readily respond to synthesized pheromones and cone and funnel traps are capable of capturing hundreds of male moths per trap per night. The present data shows that the *H. armigera* pheromone attracted high numbers of this species (up to 263 moths per trap per night) throughout the crop-growing period, which enabled us to use different IPM components to control *H. armigera* in cotton fields at two test locations (Sankarabanda and Korlagundi). Following the initial release of *Trichogramma* parasitoids there was an increase in percentage of *H. armigera* egg parasitism at both locations. Release of these parasitoids with predator, *C. carnea* eggs at 63 d.a.s. and again at 70 d.a.s. showed that there was decrease in trap catches (from 263 to 118 per trap per night) and a reduction in percentage of damage (from 34 to 25%) at both locations. REDDY and MANJUNATHA (1999) observed a high level of egg parasitism (63%) in *H. armigera* by *T. chilonis* and *T. achaea* in cotton under field conditions. Tests conducted earlier on cotton by KING et al. (1982) indicated a reduction in *H. armigera* larval population as a consequence of parasitization by *Trichogramma* parasitoids. However, the yield was only correlated

with increased parasitization in tests with tomatoes. Furthermore, he stated that no predator was currently being used to any degree for controlling *H. armigera* by augmentation. However, RIDGWAY et al. (1977) demonstrated the technical feasibility of suppressing the larval population of *H. armigera* in cotton by periodic release of *C. carnea* eggs or larvae. They observed reductions in *Heliothis* larval populations by releasing as few as 24 700 *C. carnea*/ha with high levels of pest mortality were obtained by releasing up to 494 000 predators/ha (RIDGWAY et al., 1977).

When NPV treatment at 250 LE/ha was imposed at both cotton fields at 84 d.a.s. there were significant reductions in trap catches (from 136.0 to 106.0 moths/trap per night). This showed NPV was also capable of bringing down the *H. armigera* populations although the trap catches was above the economic threshold level in the field. MCKINLEY (1982) pointed out with regard to *Heliothis* virus against *H. armigera* that, although good persistence on cotton was easily demonstrated with leaf bioassays and test insects, larval kill under very heavy attack could not be demonstrated. However, his further field trials in Republic of South Africa and Australia against *H. armigera* on cotton were very encouraging, showing yield increases comparable with those obtained with chemicals. When chemical insecticides such as mono-

Table 6. Details of the chemical treatments imposed in the farmers plots

Crop stage (DAS)	Different chemicals sprayed at:	
	Shankarabanda	Korlagundi
49	Carbaryl 50 WP at 2.5 kg/ha	Chlorpyrifos 20 EC at 2.0 l/ha
56	Monocrotophos 36 SL at 3.0 l/ha	Carbaryl 50 WP at 3.0 kg/ha
63	Cypermethrin 10 EC at 1.0 l/ha	Phosalone 35 EC at 3.0 l/ha
70	Phosalone 35 EC at 2.5 l/ha + Dicofol 25 EC at 2.0 l/ha	Monocrotophos 40 EC at 2.5 l/ha
77	–	Fenvalerate 20 EC at 0.50 l/ha
84	Endosulfan 35 EC at 3.0 l/ha	Quinalphos 25 EC at 2.5 l/ha
91	Dicofol 25 EC at 2.0 l/ha	Malathion 50 EC at 2.5 l/ha + Dicofol 25 EC at 2.0 l/ha
98	Dimethoate 30 EC 1.0 l/ha	Carbaryl 50 WP at 3.0 kg/ha
105	Methyl parathion 50 EC at 1.0 l/ha	–
112	–	Dichlorvas 100 EC at 2.0 l/ha
119	Decamethrin 2.8 EC at 0.70 l/ha	Permethrin 20 EC at 0.75 l/ha
126	Malathion 50 EC at 2.5 l/ha	Decamethrin 2.8 EC at 0.70 l/ha
131	Endosulfan 35 EC at 2.5 l/ha	Monocrotophos 36 SL at 2.5 l/ha
138	Chlorpyrifos 20 EC at 1.5 l/ha	–
145	Carbaryl 50 WP at 2.5 kg/ha	Endosulfan 35 EC at 2.5 l/ha
152	Monocrotophos 36 SL at 3.0 l/ha	–
159	–	Carbaryl 50 WP at 3.0 kg/ha
166	Quinalphos 25 EC at 2.5 l/ha	–
173	–	Endosulfan 35 EC at 2.5 l/ha
180	Endosulfan 35 EC at 3.0 l/ha	Monocrotophos 36 SL at 3.0 l/ha
187	–	–
194	Malathion 50 EC at 2.5 l/ha	–
201	–	–
208	–	–

DAS, days after sowing.

crotophos, cypermethrin and alphasmethrin were used at recommended dosages, there was highly significant reduction in trap catches (from 106.0 to 21.0 per trap per night) and the percentage of square damage (from 26.3 to 18.8%) at both the locations. These results and our aim of applying chemical pesticides at this stage was agreeable with KOHLI (1982) who reported that synthetic pyrethroids can be used as part of an integrated control programme in which their low toxicity to predators and their irritant effects on mobile parasitoids and pollinators are of major importance. UK and OUTRAM (1979) reported that monocrotophos can be used as part of an IPM programme in

cotton fields. In the present study, the percentage of *H. armigera* egg parasitism at both test locations was drastically reduced. PRASAD et al. (1987) reported that parasitism of *H. armigera* in chickpea fields was moderately affected by pesticidal treatment. However, our laboratory tests indicated their low toxicity against *T. chilonis* and *C. carnea*. The drastic reduction of *T. chilonis* in the field study could be due to cumulative pesticidal effect. Further, ecological studies on these aspects have to be conducted.

Application of NPV + nimbecidine at 112 d.a.s. and repeated again at 119 d.a.s. and dipel 81 + nimbecidine at 126 d.a.s. and dipel WP + nimbecidine at

Table 7. Yield of seed cotton and economic analysis of investment versus benefit in the IPM and farmers plots

Details	Location		
	Shankarabanda	Korlagundi	Average
Yield in IPM plots (t/ha)	2.35	2.17	2.26
Amount spent in IPM plots (Rs./ha)	2728.7	2728.7	2728.7
Gross returns in IPM plots (Rs./ha)	37426.25	36243.0	36834.6
Net returns in IPM plots (Rs./ha)	34697.55	33514.3	34105.92
Yield in farmers plots (t/ha)	1.64	1.52	1.58
Amount spent in farmers plots (Rs./ha)	7720.0	6275.0	6997.5
Gross returns in farmers plots (Rs./ha)	28725.0	27143.0	27934.0
Net returns in farmers plots (Rs./ha)	21005.0	20868.0	20936.5

152 d.a.s. successfully reduced the population of *H. armigera* below the economic threshold level at both locations. THAKUR et al. (1988) suggested that the neem seed kernel extract 2–5% formulation can be used to control *H. armigera* in place of the highly toxic synthetic insecticides because of its safety to beneficial insects and its lower cost. However, DABI et al. (1988) reported that the combinations of different insecticides and dipel had a stronger synergistic action against *H. armigera* than insecticides and dipel sprays alone. In the present studies, we found that combinations of nimbecidine (neem product) had significant effect in bringing down the *H. armigera* population at both the locations as also reported by HELLPAP and ZEBITZ (1986) in case of *Spodoptera frugiperda* and *Aedes togoi*.

5 Conclusion

Examination of results obtained in the large-scale IPM plots reveals significant superiority of integrated pest management (IPM) strategy both in cost versus benefit and environmental safety. As the results were obtained in a large area, it is convincing that the IPM is most profitable and sustainable in the management of bollworms. Therefore, it is suggested that this IPM strategy is encouraged among the farming community to safeguard the environment to encourage the natural resistance factor and lower the hazards arising from the continuous use of pesticides.

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