# New vistas in IRM based cotton IPM in India

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## ABSTRACT

*Development of a sustainable Integrated Pest Management in cotton for Indian farming conditions has been a challenging task. Despite the fact that enormous efforts have been made by the Government of India to demonstrate the usefulness of standard IPM practices incorporating biological control and appropriate need based use of insecticides, the uptake of IPM in India has only been marginal. The current paper discusses the principles that were involved in the development of Insecticide resistance management based IPM which offers a robust and practical approach to ensure sustainable implementation of IPM in Indian farming conditions. The new strategies were designed to combat insecticide resistance while ensuring effective pest management and profitable cotton production. These incorporate insecticide resistance management principles, insecticide resistance monitoring, conservation of beneficial parasitoids and predators through the use of sucking pest resistant varieties and regulated insecticide use, simplified pest scouting methods, inclusion of novel chemistries and Bt-cotton.*


## Introduction

Over the past one and a half decade, insecticide resistance in cotton pests has emerged as a key area of concern in cotton pest management in India. Most of the pest management difficulties in recent times, especially in years of bollworm outbreak, have been traced to insecticide resistance. The problem of resistance had reduced insecticides to less useful and reliable tools. If cotton pest management is to be effective, it is necessary to address the problem of resistance to insecticides, and devise appropriate proactive management strategies to ensure that it does not continue to impair pest management in the field.

The cotton bollworm, *Helicoverpa armigera* (Hübner) is a major pest of cotton causing annual yield losses in India estimated at US $290-350 million (King, 1994). Overuse of insecticides, notably the pyrethroids, was presumed to have caused outbreaks of *H. armigera* and *Bemisia tabaci* in central and southern regions of India during 1984-85, and 1987 (Reddy and Rao, 1989). By 1988 the situation had deteriorated further with no yield advantage being obtained due to pyrethroid use in cotton (Rao *et al.,* 1994). The first reports (Dhingra *et al.,* 1988; McCaffery *et al.,* 1989) on development of resistance to pyrethroids by *H. armigera*, attributed field control failures to resistance. Subsequently, high levels of pyrethroid resistance were reported in several cotton and pulse growing regions of the country (Mehrotra and Phokela, 1992; Armes *et al.,* 1992, 1996; Sekhar *et al.,* 1996). Based on a survey conducted during 1991-95, it was concluded that resistance to pyrethroids was ubiquitous across the Indian sub-continent (Armes *et al.,* 1996). A follow up survey (Kranthi *et al.,* 2001a, 2001b, 2001c, 2002) showed that insect resistance to insecticides was indeed a critical problem in several parts of the country (Table 1).

The main purpose of this paper is to highlight the extent of the resistance problem in *H. armigera* and to propose resistance management strategies that have been validated in farmer participatory programs, for large-scale use to mitigate the problem.

## Experimental procedure

### Resistance detection methods

1. **Discriminating dose assay**: The test insect population was treated with a single dose of insecticide sufficient to kill 99% individuals of a susceptible strain. The survival frequency at this dose represents percentage of a population that is resistant. This test is convenient to perform as the sample size of the test insects is much less than that required for the log dose tests. The discriminating doses used for resistance monitoring were cypermethrin 0.1 mg; fenvalerate 0.2 mg; endosulfan 10.0 mg; methomyl 1.2 mg and quinalphos 0.75 mg per third instar.
2. **Log dose probit assay**: Test insects were treated with a range of concentrations to determine the dose that can kill 50% of the population ($LD_{50}$). Comparison of the median lethal dose of the test population with that of the susceptible strain indicated resistance factors.

Resistance monitoring for *Helicoverpa* was carried out using a micro-applicator to deliver a single drop of one ml solution on each third instar larva and assessing mortality for six days. Typically, eggs from fields were collected daily, transferred onto semi-synthetic diet and the resulting third instar larvae used for assays. Collection of eggs was preferred over that of larvae, as field collected larvae usually harbored parasitoids thereby leading to artifact errors. Field collected larvae were reared to the $F_1$ third instar for testing with log dose probit assays.

IRM strategies were designed based on results of the Indian Council of Agricultural Research network project on 'Insecticide resistance management of *Helicoverpa armigera*' carried out over a period of ten years, at six different research institutions in India. The strategies place emphasis on efficient use of insecticides to conserve the ecosystem for better pest management. The dissemination of technologies was carried out as a farmer participatory program in a single village first. Based on the 'feed back', the technologies were refined and implemented in nine villages in three states for five years (Russell *et al.,* 1998) and were later spread to 260 villages all across India. To ensure farmer compliance to the strategies, a 'village voluntary participation' strategy was adopted. In the state of Maharashtra, used as an example here, as other states differed somewhat in their methods, a newspaper advertisement announced that the Central Institute for Cotton Research (CICR) would adopt villages if farmers wanted them to. The condition was, that farmers would have to bear the cost of field volunteers who were employed by CICR to stay in villages to assist farmers in cotton pest management. Further, except for advise, the CICR would not give any other material assistance to farmers as is normally done by the Government institutions in extension programs. The response was overwhelming, based on which villages were chosen for the IRM dissemination program. The CICR employed three postgraduates as research associates and eighteen undergraduate students to facilitate the program in nine villages of Wardha district, in Maharashtra, central India. A pest forecasting and insecticide resistance detection and monitoring center was set up in the district headquarters. The three post-graduates were intensively trained in Insecticide resistance management. They assisted farmers in cotton pest management throughout the cropping season. In addition 18 undergraduate students from the local Agricultural University stayed in the villages for four months throughout the cotton season as a part of their mandatory Rural Agricultural Work Experience program. A bulletin (for sale @ US $0.30 per copy) in the local language (with 47 color photographs of pests and natural enemies) on IRM strategies was published to enable farmers understand the techniques in detail. The nine villages were clustered into three groups of two, three and four villages per cluster, for operational convenience. Two students were stationed in each village. One postgraduate managed each cluster. The Research Associates stayed in Wardha, ran the resistance-monitoring laboratory and supervised the trials through regular visits. The Research Associates were required to coordinate the work in all the villages of the cluster, conduct regular meetings with farmers, impart knowledge on IRM strategies, insecticide use, insecticide application technology and augmentation of beneficial insects. A motorbike was provided for each Research Associate for site visits.

The IRM strategies utilizing the same technical principles were implemented in villages in the states of Punjab, Andhra Pradesh and Tamil Nadu and have now been widely accepted by farmers in all regions wherever introduced. Ready acceptability by farmers has been due to simplicity of the strategies and the sustainability of the technology components.

## Resistant management strategies

These area-wide farmer participatory 'Insecticide Resistance Management' strategies were disseminated in 24 villages of four cotton growing states for four years and in 260 villages of 10 cotton growing states from 2002 onwards. The IRM technology designed for implementation is a relatively simple but knowledge-intensive package. It includes farmer training in the identification of insect pests and their natural enemies, the application of economic threshold levels in spray decisions (and use of recommended sprays based on susceptibility levels) and general agronomic management. Emphasis was placed on the management of resistant pests through the use of resistance monitoring data generated painstakingly over the past seven years. This indicated the optimum materials to use for particular pests at particular times of the season. The following IRM strategies were formulated based on those scientific findings:

### 0-60 Days after sowing

1. **Cultivate sucking pest resistant/tolerant varieties/hybrids**. If needed insecticide seed treatment option can be used
   **Rationale**: Sucking pest resistant genotypes are available in abundance. It would be possible to avoid early sprays and thus conserve natural control.
2. **Do not spray insecticides, especially organophosphates on the crop (sucking pest resistant/tolerant varieties/hybrids) at least till 60 days after sowing**. If needed 5% NSKE + neem oil 1 l/ha can be used for sucking pest control.
   **Rationale**: An overall reduction in the use of insecticides retards the development of insecticide resistance. Predators and parasitoids of soft bodied sucking insect pests and other natural enemies of pests occur abundantly during the first three months of the crop. Broad-spectrum organophosphate insecticides strongly disrupt natural enemy populations. Avoidance of organophosphate insecticides for the first three months helps in build-up of entomophage populations such as *Chrysoperla, Campoletis chloridae, Microchilonis curvimaculatus* and Tachinids, which contribute to the management of *H. armigera*.
3. **Take up intercropping with cowpea**.
   **Rationale**: Cowpea was found to encourage natural enemies.
4. **Sucking pests can be tolerated to some extent**.
   **Rationale**: Some sucking pest population is necessary to sustain naturally occurring beneficial insects. Damage due to jassids or aphids, in tolerant genotypes does not have any significant negative impact on yields. A crop that is slightly infested by sucking pests is not a good host for *H. armigera*.
5. **Do not spray insecticides against minor pests such as the semiloopers, leaf folders and the hairy caterpillars**.
   **Rationale**: Semilooper and leaf folder larvae were found to cause minimal crop damage while serving as a breeding ground of generalist parasitoids that keep *Helicoverpa* populations in check.

6. **Use nitrogenous fertilizers to the minimum**.
   **Rationale**: Excessive nitrogenous fertilizers encourage sucking pests.

### *60-90 Days after sowing:*

1. **Scouting to be carried out for 50% affected plants (20 out of 40 plants)**. This is done as visual assessment based on plants having at least one flared square.
   **Rationale**: *H. armigera* infestation begins on plants just at the time of squaring and infested plants can easily be scored based on flared-square symptoms. The crop would be at peak squaring phase and the presence of each larva per plant correlates to a fruiting-point damage of 8-12%. One larva per two plants equals a damage of about 4-6%.
2. **Do not use organophosphates or pyrethroids as these can disrupt the abundant natural enemy populations, use either *Trichogramma* or HaNPV or spray only endosulfan**.
   **Rationale**: The larval stages are mostly tender and uniform and are susceptible to any of the biopesticides or endosulfan. Of all the insecticides tested, endosulfan has the lowest toxicity to abundant natural enemies. Endosulfan resistance levels have been found to be invariably low early in the season, i.e. Aug-Sept, and higher later on. This is because of the instability of endosulfan resistance, which declines in the absence of any insecticide use on them during the preceding few generations during the non-cropping period
3. **Target younger stages of *Helicoverpa* as younger stages of resistant larvae are known to be killed more easily at normal recommended doses**.
   **Rationale**: Younger larvae of insecticide resistant strains are relatively susceptible to insecticides.
4. **Avoid insecticide mixtures**.
   **Rationale**: Insecticide mixtures can devastate natural enemy populations and rarely provide improved control.
5. **Mechanically collect larvae two to three days after insecticide sprays**. This effectively eliminates any surviving population, which can cause future resistance problems.
   **Rationale**: Larvae that survive insecticide sprays generally constitute the insecticide resistant population.

### *90-120 Days after sowing:*

1. **Scouting to be carried out for affected plants**. This is done as a visual assessment based on plants having an average of one flared square or damaged boll.
   **Rationale**: The crop would be at peak boll-formation phase and each larva causes damage to 1-2 bolls, which constitutes about 5% of the bolls.
2. **Organophosphates or thiodicarb can be used as effective larvicides based on an ETL of an average of one damaged fruiting structure per plant**. Do not use endosulfan or pyrethroids during this phase.
   **Rationale**: Resistance levels against certain organophosphate insecticides (quinalphos, chlorpyriphos and profenophos) and carbamates (Thiodicarb) have been found to be low in most populations tested. Endosulfan resistance increases after the first spray. Pyrethroid resistance in *H. armigera* is high in many parts of India. Natural enemy populations are on the decline after 90-100 days of the crop, even without insecticide use. *H. armigera* larval stages are mixed, with a higher proportion of larger (4-6$^{th}$ instar) larvae, which are difficult to control with most bioagents.

### *Later than 120 days after sowing:*

1. **Use pheromone traps for pink bollworm**. Eight moths per trap per night, for three consecutive nights is the economic threshold.
   **Rationale**: The pink bollworm pheromone traps are very good indicators of pink bollworm infestation.
2. **Pyrethroids may be used later in the season in combination with sesamum oil (1 l/ha) for effective management of the late season *Helicoverpa* and the pink bollworm infestation**.
   **Rationale**: Pyrethroids are still effective on spotted and pink bollworm. Sesamum oil is a good synergist of metabolic resistance to pyrethroids and enhances the efficacy on resistant *Helicoverpa* larvae.
3. **Destroy crop residues in order to prevent carry over of pest populations**.
   **Rationale**: Keeping crop residues beyond the season encourages survival of diapausing pink bollworm populations and a subsequent attack in the following season.
4. **If it is necessary to spray more than ones, alternate chemical groups to help in preventing the build up of resistance, which is common with most insecticides, especially carbamates, organophosphates and endosulfan**.
   **Rationale**: Repeated application of the same group of insecticides speeds resistance development.

## *Results and Discussion*

### *Insecticide resistance in H. armigera*

Armes *et al.* (1996) and McCaffery *et al.* (1989) reported resistance levels of 28 and 13-fold endosulfan resistance in *H. armigera* strains from Andhra Pradesh. They observed that even low levels of five to 10-fold resistance to endosulfan were sufficient to render the chemical ineffective for *H. armigera* control under field conditions. Quinalphos resistance across the country was low, with the highest levels of 10 to 15-fold observed in strains collected from the south India. Resistance to monocrotophos ranged from eight to 65-fold, in the field strains tested. The highest resistance factors of 39 to 65-fold were recorded in the strains from north India. Out of 40 field strains, only eight were found to express resistance to methomyl, the highest being 22-fold against a strain from Prakasam district south India. The results indicated that resistance appeared to be increasing over the past two to three years in most of the strains tested. Armes *et al*. (1996) reported resistance levels of 2-38 fold to methomyl in different parts of India, with highest at 162 fold in Guntur.

LDP assay monitoring: A majority (52 out of 54 tested) of the Indian field strains exhibited resistance to all four pyrethroids, indicating ubiquitous occurrence of pyrethroid resistance in the country. Low to moderate (below 100-fold) levels of resistance were recorded in 29 of the 54 strains. Deltamethrin resistance was exceptionally high in strains collected during February 1998 from central India. Resistance to the other pyrethroids was also high in some strains with RFs of more than 1,000 in strains collected from south India. Resistance to pyrethroids appeared to have increased over 1995-1998 in most of the areas surveyed. High resistance levels were recorded in regions where pyrethroid use was most frequent (four to eight applications per season).

Resistance to endosulfan results in field failures at much lower RFs than occurs with pyrethroids. Resistance levels to endosulfan varied from four to 28-fold. Resistance was fairly high at 16 to 28-fold fold in five out of the nine strains collected in central India and was moderate at 10-15 fold in six out of 10 strains from south India. Resistance was <10-fold in strains from rest of the country. The highest levels of resistance to endosulfan were detected in *H. armigera* strains from central India. Endosulfan is the single largest selling insecticide in central India with an estimated 85% use on cotton alone. The higher use of the compound on cotton could have contributed to the high levels of resistance.

Discriminating dose assay monitoring indicated that survival frequencies to discriminating doses of cypermethrin and fenvalerate were generally above 75% in the country. Despite the steady decline in the preference for pyrethroids in cotton pest management over the past few years, resistance to pyrethroids does not appear to be on the decline. The in-season changes in resistance to pyrethroids indicated that resistance was generally low during October, but increased to higher levels during the subsequent months before declining again by the end of the cropping season. In central India, resistance to fenvalerate and cypermethrin was high throughout the season (Table 2) during 1993-99. The annual average resistance varied between 69 and 89% for cypermethrin and fenvalerate indicating high resistance. Resistance levels were relatively lower during the cotton season, especially during early reproductive phase of the crop (Sept-Oct for Andhra Pradesh and Maharshtra; Oct-Nov for Tamil Nadu and Aug-Sept for the North). This information supports the idea that pyrethroids could still be used on cotton against *Helicoverpa* infestation within a specified window period particularly on moths and younger larvae.

Resistance to endosulfan was moderately high at an average of 27 to 47% during 1993-99. Resistance to endosulfan increased consistently over the 1993-1994 cropping season from 19% in early September to 80% by mid-March. A similar trend was observed during the 1997-1998 season, when resistance increased from an average of 15% in September to 64% by November and continued to increase to 71% by mid-January. During the cropping seasons of 1994-1995 and 1995-1996, endosulfan resistance was similar and relatively constant at an average of 40-41% survival (range 26-56%), without significant fluctuations during the season. However, resistance was low at an average of 27% (range 12-52%) during the 1996-1997 season, with a perceptible increase being observed only by the end of season in April. During the 1998-1999 cropping season resistance was moderate at a seasonal average of 32 % (range 12.5-51%). However at the beginning of the season from September to mid-October, resistance levels were slightly low at an average of 22.12% and for rest of the season were at a more normal average of 34.7%.

Average resistance to quinalphos was almost consistent at seasonal averages of 24, 25, 23, 23, 27 and 25% survival during the six consecutive years from 1993 to 1999 and rarely exceeded 50% during any of the cropping seasons. The in-season changes in resistance levels to quinalphos were almost similar to those with endosulfan during the three cropping seasons between 1996-1999.

## Dissemination of IRM techniques

During the 1997-98 cropping season, farmers participatory IRM trials were demonstrated in about 30 acres with 11 participating farmers in a village Rohna, 40 km from CICR Nagpur. Two to three applications of insecticides were given in IRM fields as compared to 4-8 rounds in the farmer practice plots. The square and boll damage in IRM fields was reduced by 15 to 52 %, seed cotton yield increased by up to 59% and plant protection costs were reduced by 25 to 60%. Almost all the non-participating farmers incurred heavy financial losses in this season of relatively high bollworm pressure.

During the 1998-2001 cropping seasons, the farmer participatory IRM trials were conducted in nine villages (Karanji-Bhoge, Karanji-Kaji, Dindoda, Tuljapur, Nagapur, Takali-Kite, Digras, Zadegaon and Belgaon) near Selsura (Deoli Tq) in Wardha district in about 1200-1500 hectares with 650 farmers. Initially it was intended to demonstrate the technology in fields of only farmers indicating their willingness to try the IRM strategies. Since it was clearly informed in all villages that no inputs would be supplied to farmers, the initial response was limited only to 10-12 farmers per village who started implementing the strategies. However, by the end of the first 60-75 days, when unsprayed cotton fields of participating farmers were looking as good as those which were sprayed, the project elicited a strong positive response and majority farmers in almost all the nine villages started emulating the practices followed by the participating farmers. By the end of the season entire villages had been transformed into a participating villages, with only minor exceptions of 5-10% disinterested farmers.

The project has been very successful (Figure 2) with a significant reduction in the use of insecticides. Bollworm numbers were low across the region and, because of the counting and ETL programs, farmers sprayed only 0-1 times as compared to the usual 7-11 applications. Farmers were happy with this situation and felt that the seed-cotton yields of 1,200-1,800 kg/ha which were being harvested now with minimum insecticide use, was the best that had been obtained by them in recent times. Though the sales of insecticides in the participating-villages and the areas in the nearby vicinity fell by 60-90 percent, traders have still expressed enthusiasm for the project since it eliminated the risk of bad debt.

The farmers of the all participating villages were extremely happy as they experienced the ecological gains in terms of not having to use mixtures, expensive chemicals, putting human labor to the risk of pesticide exposure and other economic benefits associated with the simple technology. The message is believed to have spread on its own to several of the neighboring villages and there is an increasing enthusiasm for implementation of the strategies.

Since it was difficult to assess the success of the technology through comparison of participating and non-participating farmers, due to the strong influence of the technologies on non-participating farmers as well, it was decided to survey the status of insecticide use in the neighboring villages in comparison to participating-villages. This is the comparative data used in Figure 2.

The strategies for IRM, demonstrated currently, are strongly sustainable and do not have to depend on any input that is not commonly available in the market place. The IRM strategies have been specifically designed to work in worst-case circumstances and were found to be helpful in outbreak seasons when participating-farmers sprayed only two to three times as against eight to 14 of non-participating farmers. Over the past five years, farmers of all the participating villages have been using at the most two applications of insecticide sprays primarily as need-based applications. The program was expanded to 260 villages in the 26 districts, which between them consume 85% of all insecticide used on cotton in India. These districts were from the 10 significant cotton-growing states. The results from the first year of IRM implementation are given in Table 2. Insecticide use was reduced by 52% and yields increased by 10% with a 33% increase in the net profit.

## *The success story*

- More than a thousand farmers of nine villages have harvested an average of 800 to 1600 kg/hectare of seed cotton consecutively for three years 1998-2001, with just two third of the normal production cost due to savings accrued from reduction in insecticide use.
- Ninety percent of farmers sprayed none to one time, at ETLs of *H. armigera*, mostly with endosulfan, at a time when resistance of bollworm to this chemical was lowest. This resulted in 70-80 percent reduction in pest population, yet kept the natural enemy populations at reasonable levels.
- Farmers of neighboring non-participating villages had sprayed an average of seven insecticide applications and found cotton cultivation unprofitable.
- Two thousand and eight hundred farmers of 260 villages in India rigorously followed the IRM program in 2002-3 with similar success (Russell *et al.*, this volume). This number is expected to increase greatly in 2003-4.

### *Reasons for success*

1. **Simplicity**: All strategies were designed keeping the Indian farmer in mind. The message was fairly simple. Spray when necessary, based on economic thresholds and resistance monitoring information. Simple methods were devised for pest monitoring. No input was included as a part of the strategy, if it was not readily available or uneconomical or less effective or complicated to use. Strategies such as the use of a jassid resistant genotype; the avoidance of organophosphate insecticides during early phase of the crop for sucking pest control; the use of insecticides such as only endosulfan during vegetative phase and early bollworms to facilitate least ecological disturbance as endosulfan is relatively benign on most natural enemies of insect pests the use of effective organophosphates only on peak bollworm populations, enabled farmers to appreciate the value of making sensible decisions which strengthen ecological management of the pest through conservation of natural enemies.
2. **Need based**: The strategies were taken to only to those villages wherein farmers responded to an advertisement given in local daily papers. The advertisement stated clearly that CICR would work with farmers to help them solve their bollworm management problems, if they were in need of help. It was also announced that no material input would be provided as a part of the exercise. Emphasis was placed on making the best of all available options thereby leading to an overall reduction in insecticide use and avoidance of superfluous sprays.
3. **Farmer participation**: Continuous interaction of farmers with the undergraduate students and project personnel who stayed in villages was vital for the

transfer of technology. Farmers were educated on the identification and scouting of harmful and beneficial insects. Farmers were encouraged to take all decisions of pest management after a total assessment of the pest and damage status.

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*Table 1. Insecticide resistance levels of* Helicoverpa armigera.

| | Cyper. | Fen. | Decis | λ-cyh. | Quin. | Chlor. | Mono. | Meth. | Endo. |
|---|---|---|---|---|---|---|---|---|---|
| North India | | | | | | | | | |
| Bhatinda | 38 | 10 | 88 | 22 | 3 | 8 | 65 | 12 | 4 |
| Dabwali | 56 | - | - | | 4 | 6 | 39 | 10 | 5 |
| Sirsa | 54 | 90 | 336 | 59 | 4 | 11 | 39 | 2 | 4 |
| Central India | | | | | | | | | |
| Nagpur | 23–294 | 91 | 574 | 85 | 1–9 | 5–8 | 8–11 | 1–2 | 4–28 |
| Wardha | 7–96 | - | | | 1–3 | 4 | 0 | 1 | 12-37 |
| Amaravati | 395–6978 | 1445 | 14.133 | 3.734 | 4–7 | 22 | 12 | 1–2 | 4–37 |
| Akola | 255-7383 | 3.139 | 26.151 | 4.477 | 4–8 | 27 | 19 | 4–12 | 7 |
| Parbhani | 49–120 | - | - | | 3–6 | 9 | | 2 | 6-10 |
| Yavatmal | 99–256 | - | - | | 3–13 | 6 | | 1–7 | 20-24 |
| Buldana | 23–38 | - | - | | 4 | 7 | | 3 | 9-11 |
| Nanded | 50 | - | - | | 2–3 | 5 | | 4 | 12-16 |
| South India | | | | | | | | | |
| Warangal | 655–789 | 118 | 648 | 336 | 2–5 | 15 | 14 | 4–14 | 10-15 |
| Medak | 116 | - | - | | 2 | 12 | 24 | 4 | 4 |
| Karimnagar | 507 | 121 | 523 | 106 | 5 | 21 | 18 | 3 | 11 |
| Khammam | 1934 | - | - | | 4 | 32 | 18 | 11 | 13 |
| Guntur | 228–1416 | 139 | 1.331 | 1141 | 8–15 | 82 | 12 | 1–14 | 6-14 |
| Praksam | 128 | - | - | | 13 | 15 | 14 | 22 | 6 |
| Rangareddy | 36–96 | - | - | | 1–6 | 13 | 11–12 | 1–4 | 1-8 |
| Mehbubnagar | 88 | - | - | | 4 | 9 | 0 | 15 | 5 |
| Coimbatore | 69–223 | 21 | 175 | 72 | 4–6 | 9 | 0 | 1–7 | 10-12 |
| Bangalore | 58–72 | | | | | | | | |
| Dharwad | 100 | - | - | | 7 | 17 | 25 | 1 | 4 |

(Source: Kranthi *et al.,* 2001a, 2001b, 2001c and 2002).

*Table 2. Weekly resistance monitoring through discriminating dose assays. Annual average data on percentage of resistant insects in field populations of H. armigera.*

| | PAU, Ludhiana | ANGRAU, Guntur | CICR, Nagpur | ICRISAT, Hyderabad | CICR, TNAU Coimbatore, & Madurai |
|---|---|---|---|---|---|
| Cypermethrin 0.1 | | | | | |
| 1993-94 | | 95.2 | 78.8 | 83.2 | 76.5 |
| 1994-95 | | 96.7 | 88.0 | 81.9 | 77.1 |
| 1995-96 | | 98.1 | 88.4 | 88.5 | 84.6 |
| 1996-97 | | | 84.4 | 84.1 | 65.3 |
| 1997-98 | | | 81.8 | 87.2 | 40.0 |
| 1998-99 | | | 82.7 | 86.7 | 62.3 |
| Fenvalerate 0.2 | | | | | |
| 1993-94 | 72.0 | 91.7 | 71.6 | 75.2 | 73.1 |
| 1994-95 | | 91.1 | 86.7 | 74.5 | 74.9 |
| 1995-96 | | 95.6 | 84.3 | 86.9 | 75.4 |
| 1996-97 | | | 78.9 | 77.2 | 73.3 |
| 1997-98 | | | 69.0 | 81.9 | 65.0 |
| 1998-99 | | | 81.9 | 81.6 | 55.4 |
| Endosulfan 10.0 | | | | | |
| 1993-94 | 36.0 | 67.2 | 46.5 | 29.5 | 45 |
| 1994-95 | | 47 | 39.8 | 23.7 | 48.8 |
| 1995-96 | 41.0 | 54.8 | 41.0 | 35.2 | 57.3 |
| 1996-97 | 30.0 | | 27.3 | 29 | 35.5 |
| 1997-98 | 19.0 | | 46.8 | 30.8 | 45.0 |
| 1998-99 | | | 32.9 | 20.3 | 42.9 |
| Quinalphos 0.75 | | | | | |
| 1993-94 | 15.0 | 66.2 | 24.2 | 25.7 | 46.3 |
| 1994-95 | | 44.1 | 25.3 | 21.6 | 44.8 |
| 1995-96 | 36.0 | 59.7 | 23.3 | 39.9 | 45.2 |
| 1996-97 | 30.0 | | 22.8 | 32.0 | 40.6 |
| 1997-98 | 32.0 | | 26.9 | 43.3 | 75.0 |
| 1998-99 | | | 25.0 | 30.5 | 30.4 |

(Source: Podborer Management Newsletters vol 1-9, ICRISAT, Patancheru, India).

**Figure 1.** *Economics of IRM-based pest management 1998-2002. Data average of nine villages of Wardha district.*

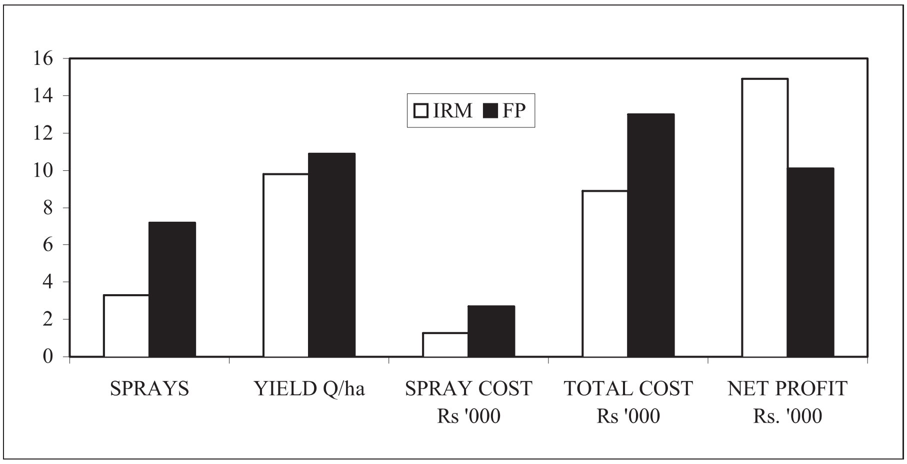


**Figure 2.** *Economics of IRM based pest management in 260 villages during 2003.*