CROP PROTECTION PROGRAMME

Development of an area-wide strategy for management of insecticide resistant cotton pests in southern India

R6734 (ZA0013)

FINAL TECHNICAL REPORT

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Project Leader: D.A.Russell
Natural Resources Institute
Central Avenue
Chatham Maritime
Kent, ME4 4TB, United Kingdom

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This project was funded by the DFID Crop Protection Programme. A research partnership, under the leadership of NRI, was operated with the Central Institute for Cotton Research (CICR) in Nagpur and Coimbatore, Tamil Nadu Agricultural University (TNAU) in Coimbatore and ICRISAT in Hyderabad, India.

1. Executive summary

In India the escalating cost of increasingly ineffective insecticide applications (c.40% of growing costs) are rendering cotton production uneconomic. As the fourth largest producer in the world, cotton provides livelihoods for 60 million people in India. Two pests; the American bollworm *Helicoverpa armigera* and the whitefly *Bemisia tabaci* account for 75% of the rapidly increasing pesticide consumption which threatens the sustainability of the crop because they have developed resistance to commonly used insecticides. The project targeted these problems by developing a strategy for optimising insect pest management on cotton via reduced and better targeted pesticides, incorporating a range of IPM and insecticide resistance management principles.

Laboratory studies of insecticide performance, including those using new nerve insensitivity techniques, increased the understanding of the mechanisms involved in resistance. A widespread programme of resistance monitoring defined the resistance pattern over the season in different regions. Pyrethroid resistance in the American bollworm was widespread and stable (more or less independently of pyrethroid use levels), with levels of up to 6,500 fold increase reported. Metabolic detoxification mechanisms are important throughout India. Additionally, reduced cuticle penetration is important in North India and nerve insensitivity is important in the heavily sprayed South. Organophosphate and endosulfan resistance were moderate at 25-40%. It appears that organophosphates and the cyclodeine, endosulfan, are cross resistant by the same mechanism. Resistance to both groups rises over the cotton spraying season but is unstable, reducing by the commencement of the following seasons. Endosulfan is an important component of project early-season recommendations because it is relatively natural enemy-friendly. Resistance to *Bacillus thuringienses* (Bt) is currently absent in India but can be selected for rapidly (7-9 generations). This has implications for the deployment of Bt transgenic cotton.

The knowledge gained in resistance studies was used to provide schedules of rational choices of insecticide depending on efficacy, the crop stage, the severity of the infestation, and the particular pest complex present (to avoid, for example, exacerbating an aphid problem by spraying a bollworm chemical which reduces natural enemies of the aphids). Spraying methods were evaluated and training provided in effective application of products which were shown to be effective. Where alternative techniques were available, these were used to avoid or delay resorting to insecticides. These measures included use of varieties which resist or tolerate sucking pests; seed treatments, and appropriate decision criteria to ensure that spraying was carried out only when pest numbers exceeded a critical level. Taken on farm, to over 1,000 farmers in 13 villages in three states in 1998-9, these integrated pest and resistance management methods allowed some impressively high reductions in pesticide to be achieved without loss of yield, making the crop more profitable and breaking the cycle of increasing insecticide use and insecticide resistance.

	Tamil Nadu	*Andhra Pradesh*	*Maharashtra*
Reduction in pesticide use (%)	46	44	95
Reduction in health hazard (%)*	77	89	92
Yield increase (%)	17	25	70
Net financial benefit Rs/ha	8,519	5,000	4,200

* Calculated on the basis of the WHO classification of the particular chemicals involved

Results and recommendations from the project were disseminated in farmer handbooks, the newsletter *Podborer*, and a series of scientific reports and media articles which reached a wide stakeholder readership. Farmer stewardship in the participatory villages carried the information to the growers using PRA driven techniques to ensure that growers not only followed the pest management methods, but understand their principles.

Cotton pest resistance management recommendations developed by the project have formed the basis of several further initiatives by the Government of India and others, including DFID which are developing and transferring the findings nationally and internationally.

2. Background

India is the fourth largest cotton producer in the world with some 60 million people deriving income from it. All-India production of cotton increased steadily from the late 1970s to reach a peak of 11.7 million bales of lint (of 170 kg) in 1986. This increase in production was primarily a result of increases in yield rather than total acreage, reflecting the development of high-yielding varieties and hybrids, improved agronomic practices and intensification of pest control measures. Since the late 1980s production has stagnated and the decline in profitability, caused by insecticide-resistant cotton pests which are very difficult to control, has been a been an important factor in this stagnation. Caterpillars of the American bollworm or gram podborer, *Helicoverpa armigera* (Hubner) are the most important insect pests of cotton in India, and a large proportion of crop losses is attributable to attack by this species. Other boll and leaf feeding caterpillars are important but more readily controlled, notably the pink bollworm *Pectinophora gossypiella (Saunders)*, the spiny bollworm *Earias insulana (Boisduval*) the spotted bollworm *Earias vitella (F.)* and the cotton leaf *worm Spodoptera litura* (F.). Amongst sap-sucking pests, the cotton whitefly *Bemisia tabaci* (Gennadius) has been rapidly gaining in importance in recent years, both for the damage it causes directly, inhibiting plant growth and contaminating cotton lint with sugary honeydew which then acts as a substrate for moulds; and indirectly, as a vector of cotton leaf curl virus (CLCuV). In recent years CLCuV has further threatened yields in North India, and the area affected by the virus is increasing.

Estimated losses to cotton pests are around 30% on average but can approach 100% in some cases. In this situation farmers tend to apply frequent sprays usually at higher concentrations than those recommended by the manufacturer. The quantity of pesticide used on cotton is increasing and has reached an average of approximately 12 sprays per season, but can be as high as 15-20. These figures mask the fact that the quantity of active ingredient per application is also rising and that many of the applications (over two thirds in 1997) are now mixtures of insecticides, often at the full recommended rate for each insecticide. This is a regional problem. Taken across Asia, cotton farmers in 1997 were expending 40-45% of total cotton growing costs on insecticides, mainly for the control of these two key pests or of secondary pest problems resulting from those applications. The increasing spiral of resistance followed by more intensive spraying has pushed most cotton growers into a situation in which they make a financial loss on their cotton production, although many are not clearly aware of this, as financial record keeping is poor.

There are a number of factors which have triggered the increase in insecticide use . The land-use pattern has intensified in the last 20 years with a greater number of potential crop hosts for both *H. armigera* and *B. tabaci* being grown in cycles which allow pest carry-over between crops. Insecticide quality is extremely variable, so sprays are frequently ineffective. The requirements of the Indian Pesticides Act for the provision by importing companies of 50% of the active ingredient of insecticides to local formulators has resulted in a plethora of small, poorly-regulated companies supplying farmers. Formulation standards are generally poor and in many cases insecticides are deliberately mis-labelled, diluted or otherwise adulterated. This results in control failures and the response has been to increase applications of alternative materials. Owing to an arcane enforcement system, successful prosecutions of corrupt manufacturers or suppliers are very few, and it is estimated that a significant proportion of insecticides on sale in India (perhaps as much as 25% in the north) are seriously sub-standard for one reason or another.

Even more significant than the quality of the insecticides is that following high selective pressure from frequent exposure to pesticides, *H. armigera* has developed resistance to many of the commonly used insecticide active ingredients. Again this has promoted the application of increasing quantities of insecticides and mixtures. A few of these mixtures are registered and produced by reputable manufacturers but most are *ad hoc* tank mixes made up by the farmers themselves (often with each component used at full rate). Proper evaluation of these mixtures has not been undertaken, but it is known that most have no enhanced efficacy over that of the best of the active ingredients alone. When used inappropriately, mixtures increase the quantity and cost of insecticides used, but can also increase the pressure for resistance selection. Even where good quality pesticides are available they may not be used by farmers, either due to dealer pressure or their higher price.

The quality of spray application is a further serious barrier to effective insect control. Local spraying equipment produced by established manufacturers is often crude, and sprayers produced by small workshops are frequently badly designed and poorly manufactured. A key problem is poor quality control of the key components such as spray nozzles. Poor spray quality and distribution exacerbates any problems with pesticide quality or insecticide resistance in the pests being treated. As in many small-holder spray situations there are also problems with the way spraying is carried out, including use of an inappropriate quantity of pesticide applied (spray calibration) and normally a complete lack of protective clothing.

Safety is an issue given an almost universal low priority in India, and many insecticides are in common use which have been withdrawn elsewhere for reasons of high mammalian toxicity. Some of the cotton insecticides are classed as moderate to highly hazardous, and the combination of high mammalian toxicity with routine operator contamination poses significant risks to users.

Although the variety of cotton can affect pest management, the suitability of the planting material is not always considered by growers and plant breeders. For example, resistance to sucking pests conferred by some cultivars has been partly ignored by breeders during the period when insecticides were largely effective.

There is a complex mix of pest management problems to be addressed in Indian cotton. A recent international report on cotton production commissioned by the World Bank, the International Cotton Advisory Committee and the Common Fund for Commodities, identified that for crop protection in India (quote): *"development of the area-wide approach to IPM, including insect monitoring, biological control and timely, efficient application of pesticides is needed",* (Gillham *et al*., 1995). The Indian Council of Agricultural Research (ICAR) identified IPM on cotton as a major research thrust (Anon, 1991).

In 1992 NRI commenced a collaborative RNRRS-funded project*, Resistance Management of Helicoverpa armigera in India* (R5745CB) with the ICAR and ICRISAT. This involved inputs from scientists from the UK and elsewhere, to monitor in detail the extent and dynamics of insecticide resistance in *H. armigera* in India. Under that project six insecticide resistance-monitoring laboratories were established with NARS institutes in key cotton and legume growing regions of India (focussing on central and southern India). Resistance monitoring focused on the key pest*, H. armigera*, with the following major objectives:

- identify the extent of the insecticide resistance problem;
- determine what chemical classes of insecticides were involved;
- record seasonal changes in resistance with a view to understanding its dynamics and mechanisms;
- identify as far as possible to what extent poor control of *H. armigera* was due to resistance rather than spray failures resulting from incorrect application, targeting the wrong life stage, incorrect choice of chemical etc.
- to provide data to assist national and state level governments in decisions on the use of agrochemicals and the management of insecticide resistant *H. armigera*;
- evaluate the success of insecticide IRM tactics once these were implemented.

Regular monitoring of resistance within this earlier project greatly enhanced our understanding of the dynamics of the problem in southern and central India. Regular patterns of seasonal changes became apparent (Armes et al., 1994; Armes et al., 1995), resulting in improved understanding of the mechanisms underlying this resistance. (West & McCaffery, 1992; Kranthi *et al*., 1994). Such data formed the foundation of the project reported here and aided its planning and execution. In a recent review of cotton research priorities, including project activities and their impact which was commissioned by the Crop Protection Programme, it was stated of the earlier work: "*It* (the project) *must be judged as having been very successful in establishing the science base for resistance management in India, for strengthening local capacity to monitor resistance levels and research mechanisms, and in raising general awareness of the resistance problem, not least amongst the agrochemical companies"* (Lyon, 1996).

Fuller information on the level and pattern of resistance was still required for the development of rational pesticide use decisions, to combat the trend by farmers to increasing the level of chemical control operations against cotton pests. Because cotton is attacked by a complex of pests it is believed that for the foreseeable future, synthetic pesticides will continue to play an important role in cotton pest management. However to be cost effective, their efficacy must be maintained, and in some cases increased, using strategies which avoid resistance selection and, where it already exists, overcome the worst effects of the developed resistance. The decision problems faced by the farmer include how best to deploy the mix of currently available technologies against a complex of pests. In other words how can farmers adopt integrated pest management (IPM).

The project needed to develop and validate a pest management system to provide a rational basis for on-farm IPM decisions. This required a collaborative programme of upstream research followed by effective farm-level dissemination to bring the technology to the cotton growers.

The stock of susceptibility in insect populations to insecticidal chemistries is a common property resource with open access. The means that it is susceptible to abuse, the 'tragedy of the commons'. Such abuse can be regulated with taxes which take the value of the uncosted stock of susceptibility into account (pigovian taxes). Another way is for people to manage such resources collectively so that the benefits which accrue to the group (rather than individual benefits) is maximised. This is the route taken by the current project.

This strategy of collective resistance management was used with great effect with the relatively small number of cotton growers (a few hundred) in eastern Australian in the late 1980s and early 1990s. Concerted action by the entire industry retained the usefulness of pyrethroids and endosulfan through voluntary restrictions on the period of use and alternation with other chemistries in an organised manner.

This particular 'social technology' would be difficult to implement in India with an enormously larger number of much less well co-ordinated farmers. The insecticide resistance management component of IPM can be distinguished from most other IPM components in several ways:

- It is concerned primarily with the management of a common property resource at an industry or community level. IPM is usually justified on the basis of private costs and benefits.
- IRM technologies are more scale-dependent than most of the technological components of IPM (even the use of pheromones for mating disruption can operate on a modest scale with most pest species).
- Compared with IPM the technological options for IRM in India are poorly defined (a long-cycle synchronous alternating area-wide strategy worked in Australia but can this function on a short-cycle asynchronous alternating insecticide-use strategy over a small area such as a village when the major pest is highly mobile, even migratory?)
- In consequence, although participatory methods may be helpful in the design and implementation of IPM strategies, participatory approaches appear to be essential for IRM to address the issue of the co-management of a common property resource.

It was appreciated that the full benefits which could accrue in terms of retention of useful chemistries, by strict adherence to recommendations by growers in in a sufficiently large block, could not be achieved on the scale of this project. *H.armigera* in particular, is highly mobile, frequently moving tens, even hundreds of kilometres between generations. The aim was to design and implement IRM strategies which would make the best use of existing susceptibility while reducing the pressure for further resistance development. This would be achieved by reducing the total insecticide pressure, linked to sequential use of non cross-resisted materials. Further social benefits of scale would accrue if and when the strategy was deployed over increasingly larger areas.

3. Project purpose

The Project Purpose *'Improved methods for the control of insect pests in cotton production systems developed',* was to be achieved by reducing the current over-reliance on conventional pesticides without compromising cotton production; by developing methodologies for an area-wide approach to cotton pest management. This Purpose was within the context of the overall Semi-Arid System Purpose of the Crop Protection Programme *'Impact of significant pests of cotton systems minimised'.*

By taking account of the constraints experienced by cotton farmers, the role of cotton in the farming system and the spatial and temporal dynamics of the pest complex, the project aimed to develop an area-wide strategy for management of insecticide resistant cotton pests in southern India. The information developed was to be used to demonstrate a practical IPM system for sustainable management of insecticide resistant pests while maintaining or enhancing farmer incomes and mitigating the risks associated with cotton growing in the region.

This project used a mixture of upstream laboratory work to develop a rational solution to the pest management decision problems faced by farmers, and a series of participatory village-based demonstrations to validate the methods and recommendations on farmers' crops. By the end of the 2.5 year project period, the project undertook to:

- Report on farmers' perceptions and cotton pest management practices, and on the socio-economic aspects affecting adoption of new management technologies.
- Transfer nerve insensitivity equipment and expertise to Indian NARS.
- Produce insecticide resistance data in support of IRM/IPM strategies and area-wide management.
- Determine insecticide resistance mechanisms and cross-resistance to insecticides in lepidopteran pests.
- Evaluate component technologies for pesticide and IRM on-station and on-farm.
- Establish principles of an area-wide approach to management of cotton pests and organised at least one pilot community-based farmer participatory trial.

The results of the work were to be disseminated through the ICAR and CICR reports, farmers' field days and extension activities, participatory training in practical techniques to empower farmers with knowledge of how to control the pests and the value of natural enemies. Project meetings, workshops and newsletters were also used. The upstream research findings were to be promulgated at national and international conferences and in journal publications.

4. Research activities

The following activities were specified in the project proposal.

1a. On-farm, farmer participatory trials at Hyderabad, Coimbatore and Nagpur to test and refine the area-wide concept for cotton pest management (years 1-2.5).

1b. Determine the scope for improving pesticide application to cotton using available equipment and evaluation of low volume technologies. Training in insecticide application to project collaborators .

2. On-station field evaluation of IPM/IRM component technologies for improved pest management in cotton at Hyderabad and Coimbatore.

3. Insecticide resistance monitoring studies at Hyderabad, Coimbatore and Nagpur.

4. Laboratory studies on insecticide resistance mechanisms and on the utility of new insecticides in cotton IPM/IRM at Nagpur.

5. Transfer of technology to evaluate the role of nerve insensitivity in insecticide resistance from Univ. of Reading to CICR Nagpur.

6a. Survey and identification of cotton farmers and operation of the cotton industry in India.

6b. Social and economic feasibility of area-wide cotton pest management and cost-benefits. Feedback of results into.

7.a. Reports, newsletters and papers.

7b. Bulletin / handbook production.

Staff inputs

To implement the above project aims, a team was assembled comprising an appropriate skill mix of entomologists, a spray application specialist and socio-economists. Inputs were made as per the project memorandum and its amendments (which allowed more widespread village participatory demonstrations than originally planned).

The project was managed from NRI by Dr D. Russell of the Pest Management Department supported by Mr J. Cooper as the insecticide application specialist. Inputs were also made by Dr D Overfield of the NRI Social Science Department. All three made at least two visits to India per year. Additional support with the resistance management work was provided Dr Alan McCaffery of Reading University, who assembled and transferred the nerve insensitivity equipment form the UK to Nagpur and trained local staff in its operation.

The Central Institute of Cotton Research laboratory and field team in Maharashtra was led by Dr K Kranthi, the pre-eminent insecticide resistance specialist in ICAR. Professor A Regupathy, Dean of the Madurai Campus of Tamil Nadu Agricultural University led the laboratory work and Dr Surulivelu of CICR, Coimbatore led the fieldwork in the southern region. Mr D Jadhav led the laboratory and field team in Andhra Pradesh, from ICRISAT in Hyderabad.

Project amendments

Project amendments provided for:

- Attendance of the project team leaders from NRI and the team leaders from the three Indian laboratories plus Dr Joginder Singh from the northern sister IRM project (R7660) to attend the World Cotton Research Conference II in Greece in 1998. Four papers deriving in whole or in part from the project were presented (Regupathy *et al.* 1998, Russell *et al.* 1998, Surulivelu et al 1998a and b) plus a further paper on cotton leaf curl virus by Singh *et al.*,(1998)

- Support for the team of field workers required for the unforeseen expansion of the IRM field demonstrations from one to nine villages in Maharashtra and one to three in Andhra Pradesh and a very substantial increase in participating farmer numbers in Tamil Nadu in 1998.

- Support for the testing at TNAU of the efficacy and persistence of *Helicoverpa* Nuclear Polyhedrosis Virus (HNPV) against *H.armigera* on cotton.

- The project leader attended the meeting on national IPM priorities in Ludhiana (28-29 Nov 1998), with seven papers on various aspects of insecticide use and IPM practices resulting (see publications section).

- The project leader to attend a conference 'Increasing productivity and quality of cotton' in May 1998 in Bombay. Paper (Russell ,1998) delivered.

- The Central Institute for Cotton Research has produced and sold for recovery of the cost on a rolling basis, 2000 of each of the copies of the English and Hindi, Marati and Tamil project colour booklet on cotton IPM as agreed (Insect Pest Control in Cotton Dec 1998 edn.). A second edition has been produced and a third is in preparation. CICR Coimbatore has further produced its own colour brochure (CICR 1998, 1999) and in 1999 the Directorate of Cotton Development has produced its own, fuller version (written by project staff) for national dissemination (CDC 1999).

- To support the provision of a training course in insecticide resistance techniques at Nagpur in late March 1998. This was successfully presented and a manual of resistance research techniques written.

- Increases in the national salary rates for research assistant and other staff in the NARS.

- Support for the analysis of environmental impacts of the project. A journal article (Iyengar and Russell 1999) has been submitted for publication covering the human health and beneficial insect impact of the IRM demonstrations in the four states covered by this project and R6760.

- Support for the attendance of the project leaders to the 'Asia Regional Consultation on Insecticide Management in Cotton' (15 countries), in Multan, Pakistan 27 May - 1 June 1999. Two papers were presented (Regupathy *et al.*, (1999) and Jadhav et al. (1999))

from this (southern) project and two (Singh, J, *et al*. 1999a and b) from the northern project.

Equipment provided

Most of the necessary equipment was available at the participating centres; some having been made available by the preceding DFID funded project.

As proposed, advanced insect nerve insensitivity detection equipment was provided at CICR headquarters in Nagpur. Measurement and monitoring of resistance was carried out and the results fed into the control recommendations which varied from region to region. Nerve insensitivity was demonstrated for the first time to be a major mechanism of insecticide resistance in India, and to be more significant in areas with higher pesticide pressure.

A laboratory microscope, a centrifuge, a refrigerator, a microbalance, incubator, microapplicators, Hamilton syringes, ELISA assay unit, air-conditioning units and insect-rearing equipment were provided to collaborating institutes.

Three motorcycles were provided to CICR to facilitate field work and, in particular, the participatory demonstrations.

A PC, printer, and software were provided to CICR station in Coimbatore from capital equipment savings. These enabled the project data to be efficiently handled and dissemination outputs generated.

It is proposed that this equipment be made available to the staff operating the Common Fund for Commodities/DFID funded cotton insecticide management project in India (2000 to 2004) at CICR Nagpur and at Tamil Nadu Agricultural University.

Research Activities

1a On-farm, farmer participatory trials at Hyderabad, Coimbatore and Nagpur to test and refine the area-wide concept for cotton pest management.

The preceding project based at ICRISAT had tested IPM strategies which took account of resistance issues with a small number of farmers, using split plot trials of less than 1 hectare at one site in the Rangareddi district of Andhra Pradesh. The aim of the project reported here was to build on this base, incorporating the results of other trials as they became available, to test and then demonstrate the feasibility and usefulness of the strategies with groups of farmers, then villages and wider areas. both at the immediate level of the individual farmer, and on a village basis and beyond. Peer pressure was known to be a major determinant of farmers pest management practice. Since sustainability, at least at the level of the individual village, was an immediate goal, it was appreciated that mechanisms would have to be found to ensure that the aims and methods of the demonstrations were understood by all farmers in the village, who would see the trials as a test of the package of practices being advocated.

The aims were to:

Increase the profitability of cotton by the inculcation of practises which would sustain or enhance yields while reducing the value of inputs in a manner which would improve the environmental and human health impact of pest management. Both short and long term benefits were to flow from the limited use of chemical insecticides; and only when required and in such a manner as to ensure their use when they were maximally efficient against the pest complex present at the time and without making the resistance development position worse.

It was also strongly felt by the project team that as the goals included sustainability over time and over considerable areas, it was important that:

- every recommended component of the strategy should itself confer a benefit to the farmer even if used alone
- that immediate, large scale reduction of the insecticide pressure was the key to achieving the major project aims
- that it would be easier to encourage farmers to do less of something they already did, in the first instance rather than to take on new components of unproven reliability, availability and cost effectiveness
- that the major hurdle to implementation would be pest scouting and that the currently recommended scouting system was impracticable.

As a consequence, in parallel with the work described below on improved technical components, a major effort was put into ensuring the village participatory nature of the work; to ensuring that the recommended practices were as simple and practical as possible; this was backed up by the provision of support for initial scouting in all demonstration villages. Emphasis was placed on simple recording of the costs and values of inputs and outputs, and on focussing the attention of the whole village and surrounding areas on the demonstration farms. To make this as effective as possible, project staff recorded the movements in pest and beneficial insect numbers over the cotton season and the precise pest management practices used in more detail than was necessary for the management of the fields..

The ICRISAT team had practical experience of the implementation of small scale IPM/IRM demonstrations and were able to move to a 20 farmer scale in the village of Ravulapally in the first project field season. The CICR Nagpur and Coimbatore teams commenced on a more modest scale. With experience, all sites expanded the scale of operations in the second season.

In all cases the villages were identified by the socio-economic team from NRI (Dr Overfield), ICRISAT (Dr Arif Ali) and Tamil Nadu (Dr Elangovan). Villages were chosen in areas in which cotton was a major enterprise, pest management was high on the farmers' agenda, and insecticide use was moderate to high. Village meetings were held to decide the form of the demonstrations and the volunteer farmers who were to participate (self selected but vetted as representative). To ensure sustainability, physical inputs were not provided, except for the unregistered imidocloprid seed treatment.

Dr Arif Ali’s (1997) report summarises the farmer social, financial and cropping situation in each of the areas. Elangovan *et al.,* (1999) examined the uptake and constraints to adoption of the project technologies.

Table 1: Structure of the IPM/IRM 'best-bet' demonstrations in 1997-98 and 1998-99

Sites	State	Season	No. of Farmers	No. of villages	Technical support	Field support model
ICRISAT	Andhra Pradesh	1997	20	1	1 scientist 2 field technicians	NGO staff
	"	1998	150	3	1 scientist 2 field technicians	NGO staff. Village IPM facilitators
CICR Nagpur	Mahar-ashtra	1997	10	1	1 scientist 2 field technicians	Direct farmer contact twice weekly.
	"	1998	650	9	1 scientist I NGO counterpart 4 field technicians	2 final year BSc Agric. Students (male) as IPM facilitators living in each village
CICR Coimbatore	Tamil Nadu	1997	20	1	1 scientist 2 field technicians	Village IPM facilitators Technical support from TNAU staff
	"	1998	81	1	1 scientist 2 field technicians	Village IPM facilitators Technical support from TNAU staff BSc Agric. Students (female) (TNAUU) making visits.

1b. Determine the scope for improving pesticide application to cotton using available equipment and evaluation of low volume technologies. Training in insecticide application provided to project collaborators .

Poor insecticide application methods and equipment make pest management more difficult and expensive. In conjunction with the northern sister project, tests of the ability of the common spray equipment used in India to provide adequate leaf coverage (upper and lower surfaces), were undertaken, supervised by Dr Cooper. The results of this work were combined with project and other information and safety precautions into a manual of spray application practice (Cooper et al 1998). This was used as a training manual in all the project villages, and in annual training courses for project farmers run by NRI staff and NARS collaborators.

2. On-station field evaluation of IPM/IRM component technologies for improved pest management in cotton at Hyderabad and Coimbatore.

- At all sites the use of imidocloprid as a seed treatment for the control of early season sucking pests was assessed. At TNAU and ICRISAT detailed measurements of plant growth and insect numbers were kept and a report prepared for the manufacturer.

The TNAU team examined the efficacy of a number of potential IPM/IRM components which had been suggested from work in the previous project.

- Cotton varieties were compared for their suitability in IPM programmes.

- The potential contribution of marigolds, planted along the bunds at the edges of the field, as a preferred oviposition site for *H. armigera*, was assessed.

- The efficacy of Pognami oil as a synergist for resisted pyrethroids was tested against commercial synergists.

- The development of simple insecticide resistance test kits was completed and the method tested for grower acceptability.

- Under a project amendment, the persistence and efficacy of HNPV against *H.armigera* was examined on cotton.

At ICRISAT

- an examination of the influence of cropping patterns into the role of the most important naturally occurring egg parasitoid, *Trichogramma chilonis*, was completed (Jadhav *et al*., submitted).

3. Insecticide resistance monitoring studies at Hyderabad, Coimbatore and Nagpur.

Routine laboratory monitoring of resistance by *H.armigera* to representatives of the main chemical classes was continued at one to two weekly intervals throughout the project using descriminating doses developed by the preceding project.

Pyrethroids:	Cypermethrin	(0.1 and 0.01 µg)
	Fenvalerate	(0.2 µg)
Organophosphates:	Quinalphos	(0.75 µg)
Cyclodienes:	Endosulfan	(10 µg)
Carbamates:	Methomyl	(1.2 µg)

In addition a survey of insecticide resistance in the main cotton pest lepidoptera plus whitefly, was undertaken in central and southern India by CICR and ICRISAT.

Bollworms:	American *(H.armigera*); pink *(Pectinophora gossypiella*); spiny *(Earias insulana)* and spotted *(Earias vitella*
Leafworms:	Cotton leafworm *(Spodoptera litura)*
Sucking pest:	Cotton whitefly *(Bemisia tabaci)*

This was a response to the devastating and uncontrolled outbreaks in 1996 of leaf feeding caterpillars (*Spodoptera litura*) and bollworms (esp. *H.armigera*) which were widely reported to have been responsible for the bankruptcy of many small cotton farmers in central India (and especially in coastal in inland Andhra Pradesh) and for several hundred resulting suicides. Weather was clearly an important factor, with unseasonal rains contributing directly to a poor crop and indirectly through enhanced pest numbers, but the role of both substandard insecticides and insecticide resistance were widely implicated.

The results were disseminated in the editions of the *Podborer Newsletter*, mailed to interested Indian and international scientists and presented at national and international meetings (see publications list)) and incorporated into the IRM strategy being developed.

4. Laboratory studies on insecticide resistance mechanisms and on the utility of new insecticides in cotton IPM/IRM at Nagpur.

Work was undertaken at the CICR laboratory to investigate the patterns and significance of the various mechanisms of resistance to the commonly used insecticides (metabolic – via esterase and oxygenase enzymes; insensitive target site – via nerve sodium channel modification). The extent of synergism was examined with a range of chemicals (cytochrome P450, b5, p420, O-demethylase, esterase and glutathione transferase), known to undermine resistance by particular mechanisms. Direct electrophysiological measurement of nerve insensitivity was made on larvae using the project acquired equipment. Routine examination the relative importance of esterase mediated and mono-oxygenase-mediated resistance was also made at the ICRISAT and TNAU laboratories.

Laboratory and field investigations were carried out into the value of the neo-nicotinyl systemic insecticide, imidocloprid (from Bayer). This material has the capacity to control sucking pests (in particular jassids and aphids) for 40-60 days after planting. By delaying the need for broad spectrum sprayed insecticides and so protecting the beneficial arthropod fauna in the cotton fields, imidocloprid had the potential to play an important role in the proposed cotton IPM/IRM programme. Imidocloprid was in registration trials during the project period. Nonetheless Bayer kindly made small quantities of the material available for farmer use in the IPM demonstrations. A report on the performance of imidocloprid in the demonstrations was provided to Bayer (Wood *et al.*, 1998). The material was registered in 1999 and is now widely available. However, the company has restricted its availability to pre-treated seed and at a price which makes it economic mainly on the hybrid cottons which are planted at lower densities than the varieties. Nonetheless as competitors come into the market e.g. thiomethoxam (novalurone) from Novartis, it is expected that availability will increase and price fall.

Work was undertaken at CICR Nagpur on the important new, fungally-derived, insecticide, *spinosad*. Spinosad shows a good activity activity against a range of insect groups. More importantly from the current perspective, spinosad has been shown to cause excitation and presistent activation of nicotinic acetylcholine receptors and prolongation of acetylcholine responses in neurones by a mechanism which distinguishes this chemical from all other nicotinic agonists. It therefore has the potential for great significance in resistance management strategies.

5. Transfer of technology to evaluate the role of nerve insensitivity in insecticide resistance from Univ. of Reading to CICR Nagpur.

With the assistance of Dr Alan McCaffery of Reading University (who developed the technique), a set of equipment for nerve insensitivity measurement was purchased from NRI and transferred to the CICR Nagpur laboratory in support of its development as an Indian 'centre of excellence' in resistance work. Dr McCaffery made a short visit to set up the equipment and instruct project staff in its operation. The equipment has been used to confirm and map the presence of evolved resistance through nerve insensitivity in Indian *H.armigera*. Nerve insensitivity appears to be a major mechanism (accounting for perhaps 25% of the total resistance), in southern India, where it appears to be stable, even in the absence of sustaining selection pressure from insecticides.

6a. Survey and identification of cotton farmers and operation of the cotton industry in India.

In the first project year a full analysis of the farmers and farming systems in the project areas in the three states of Maharashtra, Andha Pradesh and Tamil Nadu, was undertaken by the ICRISAT socio-economist, Dr Arif Ali (Ali, 1997). This study underpinned the choice of project villages, the participatory methods employed and provided the baseline from which the impact of project practices was measured.

6b. Social and economic feasibility of area-wide cotton pest management and cost-benefits. Feedback of results into 1-2.

A draft paper on the implications of the concept of 'Area-wide' application of IPM practices in cotton was prepared by Dr Arif Ali and Dr Cox of ICRISAT. However, the disbanding of the IRCISAT social sciences sections in 1997 prevented the completion of this work. Some of the more pertinent conclusions are discussed below.

Dr Elangovan of TNAU undertook an examination of the constraints to the adoption of the recommended IPM/IRM practices in the project villages in the three states (Elangovan 1998) (project report). With the addition of studies form the northern sister project in the Punjab, this is reported in Elangovan *et al*.,(submitted 1999) and Elangovan and Overfield (submitted 1999).

7a. Reports, newsletters and papers.

The project's own newsletter *'The Podborer'* carried the results of the laboratory and field work at each site to the professionally interested audience. Project reports were produced on the socio-economic dimensions of the work, the progress in component technologies. A total 20 national and international conference and meeting papers were presented to April 1999 on all aspects of the work and 9 journal articles submitted on the nature and extent of insecticide resistance in India, the prospects for adoption of the developed practices, and the IPM/IRM demonstrations in the project villages. *(See the Publications section for details).*

7b. Bulletin / handbook production.

The farmer and local extension worker level, partners were provided with a series of colour brochures on cotton pest management in English, Hindi, Marati. Tamil and latterly Punjabi (CICR 1998, 1999). These were produced at CICR Nagpur and sold to interested parties at 15 Rs (25p)/copy. The first edition sold out very rapidly and it has now been reprinted three times, using the capital generated by the earlier sales. An early attempt to produce a poster and literature for distribution through the pesticide dealer's network, in conjunction with the industry body, (the Insecticide Resistance Action Committee), failed at the last moment due to an insistence by the IRAC member companies that all the registered chemicals available against particular insects be displayed, and not only those felt by the project team to be the most appropriate in terms of efficacy, quality and resistance impact.

Professional scientists have been provided with a manual of insecticide resistance identification, monitoring and management techniques (Kranthi and Russell in press) and journal and meeting papers (see outputs and publications sections for details).

5 Outputs

The outputs were:

- Established principles of the area-wide approach to management of cotton pests and at least one pilot community-based farmer participatory trial organised.
- Component technologies evaluated for pesticide and IRM on-station and on-farm.
- 'Centre of excellence' in insecticide resistance mechanisms and bioassay technologies supported.
- Production of insecticide resistance data from at least three locations on a limited scale in support of IRM/IPM component technology testing and to provide baseline data in support of the area-wide approach to pest management.
- Determination of insecticide resistance mechanisms and cross-resistance to insecticides in lepidopteran pests.
- Transfer nerve insensitivity equipment and expertise to at least one Indian NARS to aid understanding of resistance mechanisms in major lepidopteran pests.
- Report on farmers' perceptions and cotton pest management practices, and on the socio-economic aspects affecting adoption of new management technologies.
- Scientific publications, bulletins and pest handbooks

All the above were achieved and in most cases significantly exceeded. Research findings developed by this project and its sister project *A systems approach to sustainable insect pest management in irrigated cotton in India,* were translated into proven recommendations for growers. Cotton pest management information was incorporated into a set of IPM or 'best bet' farmer practices which the project then demonstrated in a number of community-based farmer participatory trials which had involved 25 villages in four states by the final year (three states and 14 villages in the southern project). Participatory methods were used to involve and coach over 1,000 farmers in a series of village-based participatory training exercises based in important cotton areas. Their knowledge, confidence and experience increased due to regular contact with project staff through the growing season and some impressively high reductions in pesticide use were achieved without loss of yield. The cycle of increasing insecticide use accompanied by increased insecticide resistance was broken, making production of the cotton crop in India much more potentially sustainable.

Established principles of the area-wide approach to management of cotton pests and at least one pilot community-based farmer participatory trial organised.

Drawing on the detailed laboratory and field entomological and socio-economic work and with the background of research and testing of viable IRM technologies form the preceding project, an effective strategy for integrated pest management involving varietal and agronomic components was developed and tested on-farm. This was successful and attracted such interest from farmers and eventually adopted by the Government of India and the Cotton Corporation.

Once the optimum recommendations had been assembled, participatory methods were used to achieve take up by cotton growers. This process involved meeting farmers and convincing them of the value of the proposed measures, and inviting them to participate. Those who did were supported. Project staff implemented the programme and helped to orchestrate suitable non–project inputs. Farmers were trained in decision making, what pesticides to use, when to use them and how best to apply them. Project staff were the key training and scientific resource for this work and the project provided

IPM strategies

It is clearly a long term goal of IPM strategies to work towards a crop management system which does not involve the addition of toxic materials to the environment and a great deal of work has been undertaken in India and elsewhere to develop varietal, cultural, biorational and biological control components of an IPM package for cotton. The continued use of materials, many of which are now banned elsewhere in the world on environmental and health grounds, is not something which should be supported. Even endosulfan, used at the rates recommended in India, has a WHO class II (moderately hazardous) rating.

The Indian cotton system has been severely altered by the intensive use of pesticides in recent decades. Even where pesticides are not sprayed at all, as on a 250 acre block in the Indian Punjab in 1997, numbers of beneficials can often be almost vanishingly low (J.Singh unpublished data). The short term need is to reduce the insecticide pressure, especially in the early season and from broad spectrum materials, in order to allow the beneficial fauna to recover its role, in addition to reducing the resistance selection pressure.

National trials have been underway for some years now to test the efficacy of various treatments ranging from ‘fully non-chemical’ to ‘fully chemical’. The importance of neem based products, NPV, *Bt* and the use of *Trichogramma* sps. as egg parasitoids, marigold and other plants as trap crops for *H. armigera* eggs has been explored. A great diversity of results and recommendations has arisen from these trials and considerable success is being achieved on an experimental basis. The use of neem in particular, especially where egg numbers are low, seems to be beneficial. Sundaramurthy and Uthamasamy (1996) provide a comprehensive review of integrated management of pest insects in Indian cotton and highlight a number of non-chemical successes. However, it is our understanding that the overall analysis to date of the national trials in the ICAR programme for the development of IPM packages under selective crop conditions, shows conventional insecticide-based cotton pest control, judiciously applied, to be still the most reliable and cost effective way of maintaining yields in most areas and years. Alongside many other Indian initiatives, the current project explored the use of trap crops, intercropping, oviposition deterrents and NPV. However, the availability of reliable products of proven efficacy at economic costs is not such as to make it currently responsible to recommend them for wider farmer use.

The use of artificial pheromone for mating disruption of *H.armigera* has been a topic of interest for some years. Recent trials in the Indian Punjab have shown that mating suppression within cotton blocks is achievable. However, immigration of large numbers of mated females in September rendered the within-block control irrelevant and egg numbers quickly rose to levels indistinguishable from those in the farmer practice control areas (J.Singh *pers. comm*). Given the highly mobile nature of *H. armigera* adults this is not perhaps surprising. It does suggest that pheromone control by mating disruption is not likely to play a direct role in the management of this species in areas subject to immigration, though reduced insecticide applications as a result of control by mating disruption of other bollworm species such as pink bollworm (*Pectinophora gossypiella* (Saunders)) and the spiny and spotted bollworms (*Earias* sps.) may have a role to play in the future.

'Best-bet' IPM/IRM trials

Picking up on the results of work at ICRISAT in 1992-5, an expanding series of demonstrations was made in farmers fields in the 1996-7, 1997-8 and 1998-9 seasons. The scale of operations increased from 20 farmers in one state in 1995 to over 1,000 farmers in 13 villages in 3 states in 1998. Full recommendations are given in annex 1 and 2. In outline the system comprised:

- *Cotton variety* - tolerant to sucking pest; semi okra leaf; short and compact stature; ability to compensate for early season pest damage
- *Agronomy* - adequate spacing; optimum use of fertilisers; removal of terminal shoots at 90 days.
- *Insecticide application* -avoid early season applications to plant (used systemic insecticide - Imidocloprid); twice weekly pest scouting; 1-2 pyrethroids per season; alternate chemical groups in successive spray rounds; do not retreat spray failures with the same chemical.
- *Resistance monitoring* - use monitoring data for decisions on which chemical groups to apply on the basis of resistance gene frequencies at that time of the season.

The trials were undertaken by the village community and project staff were based in the area to ensure continuity of advice to the farmer, who was to make the pest control decisions based on his own scouting, supplemented by advice from project staff, especially in the first year.

The practical components of the IRM methodology implemented by the farmers for central and southern India are summarised below. Full season recommendations are presented in Annex 1. Recommendations took into account existing University and state recommendations for IPM and local knowledge of the efficacy of particular materials within an IRM context.

Seed: Use certified varieties or hybrids which are tolerant to sucking pests.
Spacing: wide spacing (specified).
Assisting beneficial organisms: delay spraying toxic material as long as possible; use seed treatment to remove the need for early sucking pest sprays.
Fertiliser: Need based after soil analysis (details provided); avoid excessive nitrogen.
Spray decisions: Not to use calendar spraying; follow thresholds below which applications have been shown to be uneconomic; rotate chemical groups; do not retreat control failures with members of the same chemical group.
Manual control of large bollworm larvae: (difficult to kill with chemicals) Hand pick before spraying and again 3 days later; squeeze *Earias* larvae in the shoot tips.
Sampling: weekly sampling of 50 plants (method and objectives provided).
Chemical control: Use only materials from the list provided (a.i. and manufacturers) and in the order suggested for particular pest problems.
Chemical control thresholds:
Sucking pests: Spray action thresholds provides for jassids, thrips, whitefly.
*Bollworms**:** Helicoverpa* egg action threshold of 1 per plant. For larvae, recommendations differ with stages in the crop phenology.
Before squaring: *Earias vitella* is the main problem and a threshold of 5 damaged tips per 50 plants is provided for mechanical control.
Main squaring period: plant examinations and shed fruit collections. Spray at one live larva per plant or 10% of fruit showing damage.
Green and open boll period: Sheds and all bolls on 50 plants examined for fresh bollworm damage. Spray at 5% *H. armigera* or 10% bollworm damage overall.

A list of the chemicals which are considererd to be effecitve against the major pest of cotton is given in Annex 2. In particular village trails farmers were recommended a limited choice of available materials, to be applied if required in a particular sequence.

Table 2: *Control Schedule* (simplified) **for the central and southern Indian 'best-bet' trials 1987-8** (need-based; alternatives for a given spray round are in order of preference)

Spray round	Pest	Common name	Total dose per acre
Pre-planting	Sucking pests	Imidocloprid	5.25g
1	Jassids/aphids	Methyl demeton 25 EC	400ml
		Dimethoate 30 EC	550ml
		Acephate 75 SP	250-300g
2	Low bollworm egg or larval numbers	Neem	as recommended
	High egg numbers	Profenofos 50EC	500ml
3	Ist bollworms	Endosulfan 35 EC	600ml
4	2nd bollworms	Quinalphos 25 EC	800ml
		Chlorpyrifos 20EC	800ml
5	3rd bollworms	Carbaryl 50 WP	800g
		Thiodicarb 75 WP	300g
6	Last bollworms	Cypermethrin 25 EC	210ml
		Fenvalerate 20 EC	220ml
		Deltamethrin 2.8 EC	220ml
		Lambda cyhalothrin	180ml

If present and over threshold at any time

Whitefly	Triazophos 40 EC	450ml
	Neem	as recommended
Mites	Ethion 50 EC	400ml

The details of these recommendations may well be modified in future years. The principles of applying good quality, appropriate materials in recommended quantities, on thresholds and in a sequence of types of a.i. are what matters. In a simplified form, these recommendations were enshrined in the local language farmers' brochures produced.

Technology dissemination was relatively simple in principle. It included 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 five years. The monitoring data maps seasonal changes in resistance to various groups of insecticides and was derived from bioassays using larvae reared from about 700,000 field collected *H.armigera* eggs. Other pest management tools such as releases of *Trichogramma, Chrysopa* or Bt, NPV etc. were not strongly promoted, as these are either relatively expensive, unavailable or of poor efficacy efficacy.

1995-6 and 1996-7 Seasons

Prior to the commencement of the current project the ICRISAT/NRI team explored the benefits a number of the components of the strategy in small scale, split-plot trials in Ravulapally village in the Rangareddy district of Andhra Pradesh in 1995-96 and both there and in Tamil Nadu in 1996-7.

Andhra Pradesh
In 1995-6, the average number of insecticide applications was reduced to 13 compared with the farmers' practice of 17; the amount of a.i reduced by 57% and the yield slightly enhanced by 5%.

In 1996-7, at the commencement of the project, emboldened by the previous year's experience, the farmers practice on the split plots used only 13 sprays. However, the project plots required only 8 sprays for a 35-40% reduction in a.i. used and a 30-42% yield increase.

It was these experiences which gave the confidence to expand the IPM/IRM demonstrations to a village participatory scale in 3 states in the first full project season (1997-8).

1997-8 Season

During 1997, farmers participatory IRM trials were demonstrated by CICR Nagpur in 11 farms in Rhona village, Maharashtra,;with 20 farmers in Palani district, Tamil Nadu by CICR Coimbatore, and 20 farmers in Ravulapally village in the Rangareddy district of Andhra Pradesh by ICRISAT.

Tamil Nadu
A Kalipattay village meeting chose 20 representative farmers for work with the CICR and TNAU teams. Regular training and scouting suport was provided throughout the season, with emphasis placed on the enhancement of independent decision making by farmers.

Table 3: Impact of the IPM/IRM programme at Kalipatty village, Tamil Nadu, 19978-98 season

Particulars	Project farmers	Control farmers	% Redn. or increase
1 No. of sprays	5.2	9.7	-46%
2 Insecticide used Kg/ha	3.4	7.2	-53%
3 Plant protection cost Rs/ha	3,200	8,800	-64%
4 Boll damage %	10.2	14.6	-30%
5 Seed cotton yield Kg/ha	2,600	2,000	+30%

As a consequence, net profit for the participating farmers rose by 29%, or Rs 7,200/ha

Andhra Pradesh
At the suggestion of the socio-economic team, the 1997-8 trials were moved to Sankepally village in the same district, because of the much stronger cotton and pest management focus of the farmers. With the almost daily support of three technical staff, convincing results were achieved.

Table 4: Impact of the IPM/IRM programme at Sankepally village,Andhra Pradesh, 1997-98 season

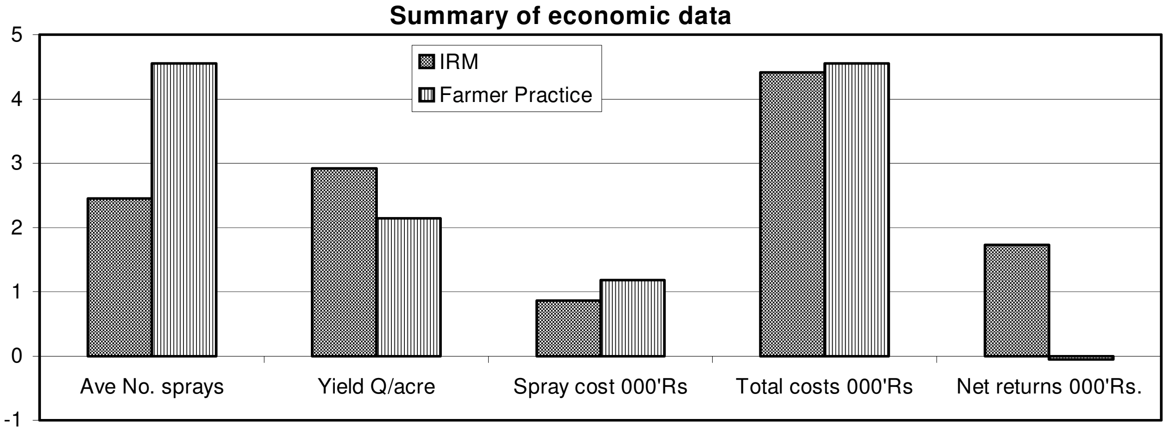
Particulars	Project farmers	Control farmers	% Redn. or increase
1 No. of sprays	9	16	-44%
2 Insecticide used Kg/ha	11.644	17.230	-32%
3 Seed cotton yield Kg/ha	1,497	1,127	+32%

Profitability increased by an average of Rs 2,400/ha.

These benefits were demonstrated at a major farmer's meeting at the end of the season, which resulted in requests from neighboring villages for the programme to be expanded in 1998.

Maharashtra
Trails were taken up in c.18ha of 11 farmers' fields in Rhona village, c. 40 Km from CICR. Reductions in spray usage and improvements in economic returns were excellent. However, with experience it was realised that this area was not as cotton dependant, nor was the cotton as badly attacked by pests, as it was in many villages in the state, and the demonstrations were moved in the following year.

Fig. 1: Impact of IPM/IRM programme at Rhona village, Maharashtra, 1997-98 season.



1998-9 Season

Tamil Nadu

Work focussed on Kalipatty village in the Palani district but in this second project year all the farmers in the village participated. TNAU staff provided soil analysis facilities for all farmers prior to the season and considerable efforts were made to ensure the supply of good quality seed of appropriate sucking pest tolerant varieties. Although the involvement of a class of female BSc students from Maduarai as village IPM leaders was not a success (their regular involvement seemed to be socially difficult both for them and the farmers), the appointment of local sons of farmers as three IPM co-ordinators, supported by CICR junior staff based in nearby Palani, worked well.

Compared with the farmers in the nearby control village of Manjanaickenpatty, insecticide use was reduced considerably and yields enhanced.

Table 5: Impact of the IPM/IRM programme at Kalipatty village, Tamil Nadu, 1998-99 season.

Particulars	**Project village Kalipatty**	**Control Village Manjanaickenpatty**	**% Redn. Or increase**
1 No. of sprays	6.3	11.6	-45.6%
2 Insecticide used Kg/ha	3.210	5.581	-42.4%
3 Plant protection cost Rs/ha	4,703	7,762	-39.4%
4 Boll damage %	9.9	16.0	-38.1%
5 Seed cotton yield Kg/ha	1881	1608	+17.0%

A 10-30% decrease in sucking pest numbers over the season, a 30-40% decrease in *H.armigera* numbers and an increase in ladybird and spider predators of 30-40% resulted; which no doubt contributed to the yield increase.

Andhra Pradesh
Project work as expanded to cover the neighboring villages of Parveda and Madikattu and c.200 farmers actively participated in the 1998-9 programme.

Table 6: Impact of the IPM/IRM programme at three villages in the Ranga Reddy district, Andhra Pradesh, 1998-99 season.

Particulars	**Project villages**	**Control Villages**	**% Redn. or increase**
1.No. of sprays	7	14	-50%
2.Insecticide used Kg/ha	6.518	21.016	-69%
3.Seed cotton yield Kg/ha	1,333	1,012	+31%

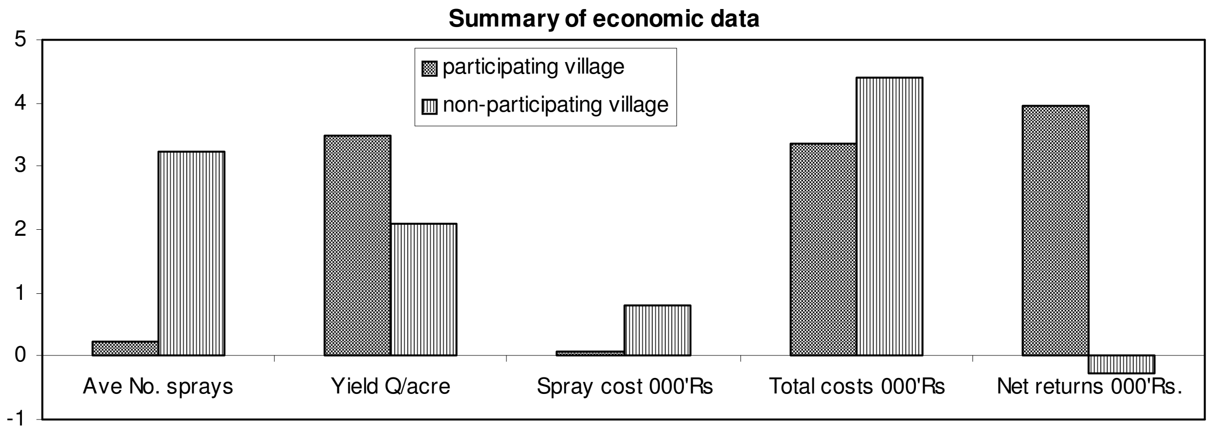
This situation resulted in a net 4-6,000Rs/ha increase in income for project farmers over those in surrounding villages.

Maharashtra
During 1998, 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 of 650 farmers. This district is known for heavy insecticide use and for the primacy of cotton in farm economics.

A pest forecasting and insecticide resistance detection and monitoring centre at Wardha headquarters close to the villages of operation. Three junior project staff (research associates) who trained and assisted farmers in cotton pest management throughout the cropping season. In addition 18 undergraduate students from Akola University were stationed in the villages for three months throughout the cotton season. The nine villages were clustered into three groups of 2, 3 and 4 villages per cluster, for operational convenience. Two students were stationed in each village. Each cluster was managed by one Research Associate. The Research Associates stayed in Wardha and supervised the trials through regular visits. The Research Associates were required to co-ordinate 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. The students were expected to work closely with farmers, participate in their day to day activities of cotton production and pest management and to train and help farmers in scouting of insect pests. An orientation training programme on Insecticide Resistance Management of cotton pests, was organised at CICR for the students. A four day training programme was run at Wardha for the students and Research Associates by Jerry Cooper, NRI, on insecticide application technology and IRM techniques.

Two meetings were held with Pesticide dealers to brief them on the strategies and to request their participation and help in the transfer of technology. Nearly 100 dealers participated in the programmes. Farmer meetings were held regularly in the villages during evening hours to discuss their problems associated with pest management and their willingness to participate in the programme. Mr Atul Sharma, director of the local of the community polytechnic and Chetna Vikas (NGO), took lead in organising IRM orientation programmes for farmers under the title of 'SHIVARPHERI' (Know your fields). A one day introduction to the programme was conducted in each of the participating villages with participation of farmers also from neighbouring villages. The programme started with 10-20 agreed participants per village at the beginning of the season. By the end of the season entire villages had been transformed into a participating villages, with only 5-10% disinterested farmers. Farmers sprayed 0-1 times as compared to the usual 7-11 applications. Though the sales of insecticides in the participating villages and the areas in the nearby vicinity fell by 60-90 per cent, traders have still expressed enthusiasm for the project since it eliminated the risk of bad debt.

Fig. 2: Impact of the IRM/IRM programme in 9 villages in the Wardha district of Maharashtra, 1998-99 season.



Dissemination was sufficiently effective for even the nearby 'control' villages to have reduced pesticide consumption by 50% compared with more outlying areas and their normal spray practices.

Table 7: Summary of Best-Bet' field trial results

1987-8 season

	Particip. villages	Spray nos. down	Yield increase	Health hazard down	Net profit increase for participating farmers Rs/ha
Tamil Nadu	1	63%	34%	77%	7,200
Andhra Pradesh	1	44%	39%	89%	2,400
Mahar-ashtra	1	55%	38%	98%	3,720

1998-99 season

	Particip. villages	Spray nos. down	Yield increase	Health hazard down	Net profit Rs/ha	
					P	NP
Tamil Nadu	1	46%	17%	77%	13,050	4,079
Andhra Pradesh	3	44%	31%	89%	13,846	4,257
Mahar-ashtra	9	95%	70%	92%	8,333	-714

'Secrets of Success' of the field work

1. **Simplicity**: 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, uneconomical, of poor efficacy or complicated to use. At is simplest the strategy comprised:
   (a) use of jassid resistant genotypes or seed treatments to avoid spraying for 60 days after planting.
   (b) avoidance of organophosphate insecticides during early phase of the crop for sucking pest control (up to 90 days after planting),
   (c) use endosulfan only during vegetative and early fruit phase (up to 90 days) to minimise ecological disturbance.
   (d) use effective organophosphates only on peak bollworm populations
   (e) delay the use of pyrethroids as long as possible (after 110 days) to retain efficacy against other bollworms.

Table 8: Simplified spray management schedule for central India

Days after sowing				
0-60	60-90	80-90	90-110	110-130
Zero spray	Endosulfan	Bio-sprays	OPs	Pyrethroid

2. **Need-based** : The strategies were taken to only to those villages where examination showed that insecticide cost was a severe constraint to economic cotton production. Insecticides were applied only when pest or damage action thresholds had been exceeded.

3. **Farmer participation** : Continuous interaction of farmers with project personnel (preferably staying in the 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.

Environmental benefits:

It was foreseen in the project memorandum that major positive benefits to the environment would accrue from reduced reliance on, and more efficient use of, pesticides in cotton ,which currently account for over 50% of insecticide used in India. Reduced applications would be of benefit to the health of farmers and field laborers and the village community as a whole through reduced environmental contamination. No negative environmental impacts were envisaged.

An analysis was undertaken of the impact of 'best bet' practices on the quantity of active ingredient of the various insecticides sprayed in the final year demonstrations. Participating farmers used far fewer mixtures of insecticides (fig. 3). The effect on total insecticide applied to the environment is shown in fig. 4.

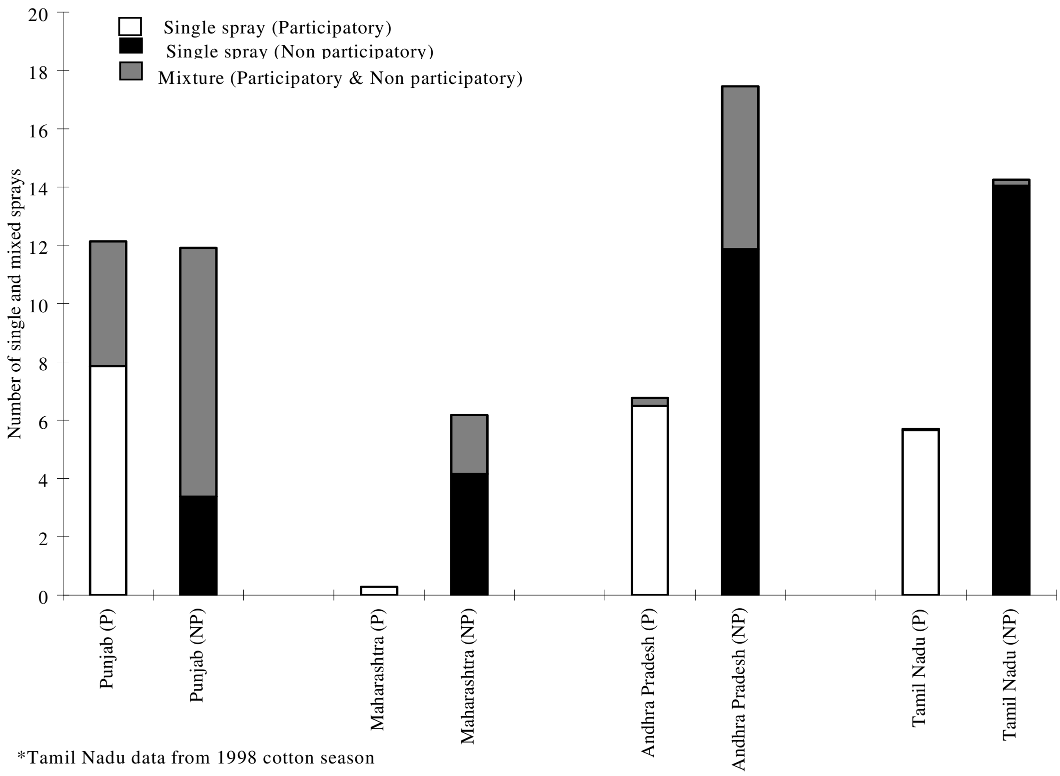


Figure 4: Number of single and mixed sprays used by participators and non-participators in the 1997-8 in Tamil Nadu and 1998-99 inAndhra Pradesh, Maharashtra and the Punjab

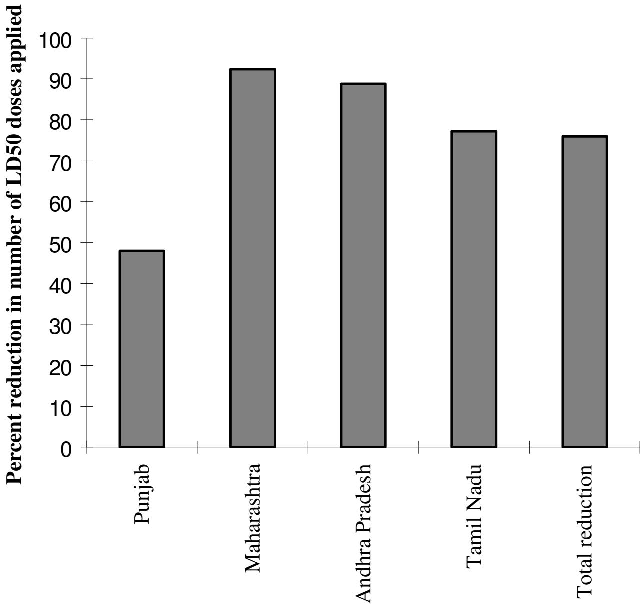
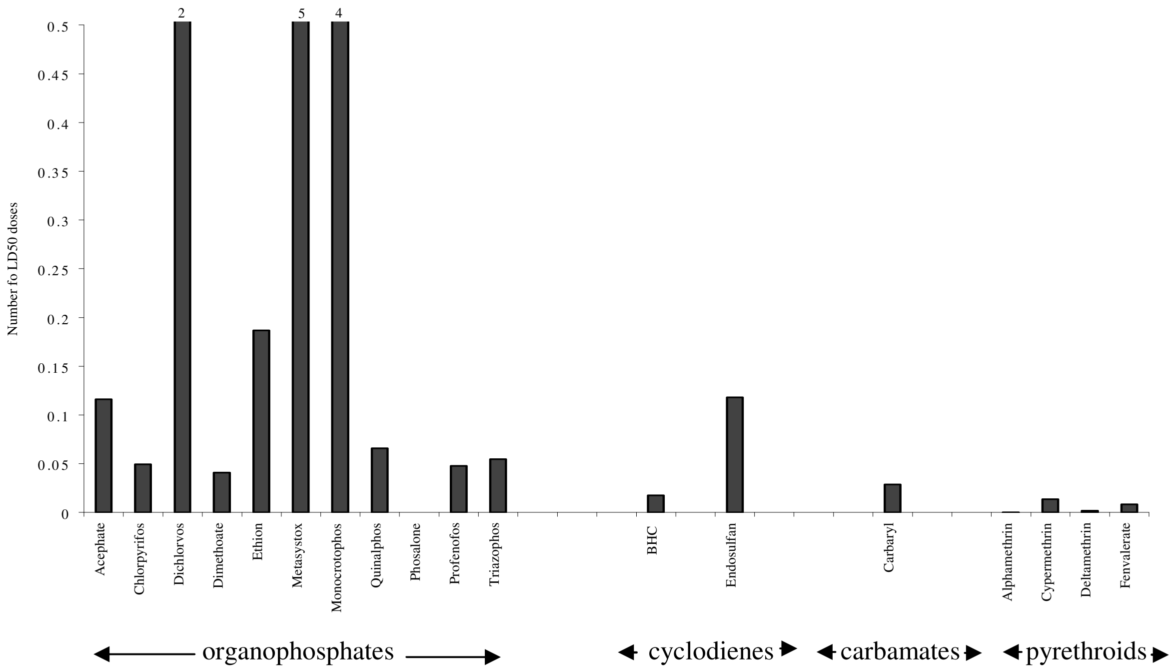


Figure 5: Percentage reduction in the number of human LD50 doses applied in the IRM farmers' fields versus those of non-participators.

More pertinently, if the mammalian toxicity of the materials sprayed is taken into account, the number of human lethal doses can be calculated. As the project deliberately minimised the use of the most toxic materials, the impact reduction in human health terms can be seen in fig. 5. It is worth noting that the organophosphate insecticides are responsible for 96% of the human hazard tabulated in these villages. The pyrethroids, which have such a bad press in terms of their impact on non-target arthropods and were sprayed more frequently than the organophosphates, were responsible for less than 1% of the human health hazard, emphasising the need to try to retain their efficacy. Over the four project states, human health hazards were reduced by 76% for participating farmers in 1998 and over 95% in Maharashtra.

Further benefits accrue in terms of the impact on non-target arthropods, especially beneficial insects which are predators or parasitoids of the pest lepidoptera. The reduction in impact on these comes particularly though the avoidance of early season spraying of broad spectrum materials via the use of sucking pest tolerant genotypes and systemic seed treatments. The estimated total impact on beneficials (using the published LD_{50}s), was reduced by 85% for egg parasitoids, 62% for larval ectoparasites, 78% for ladybird predators and 63% for lacewing predators (Iyengar and Russell 1999).

A Non- participatory farmers



b Participatory farmers

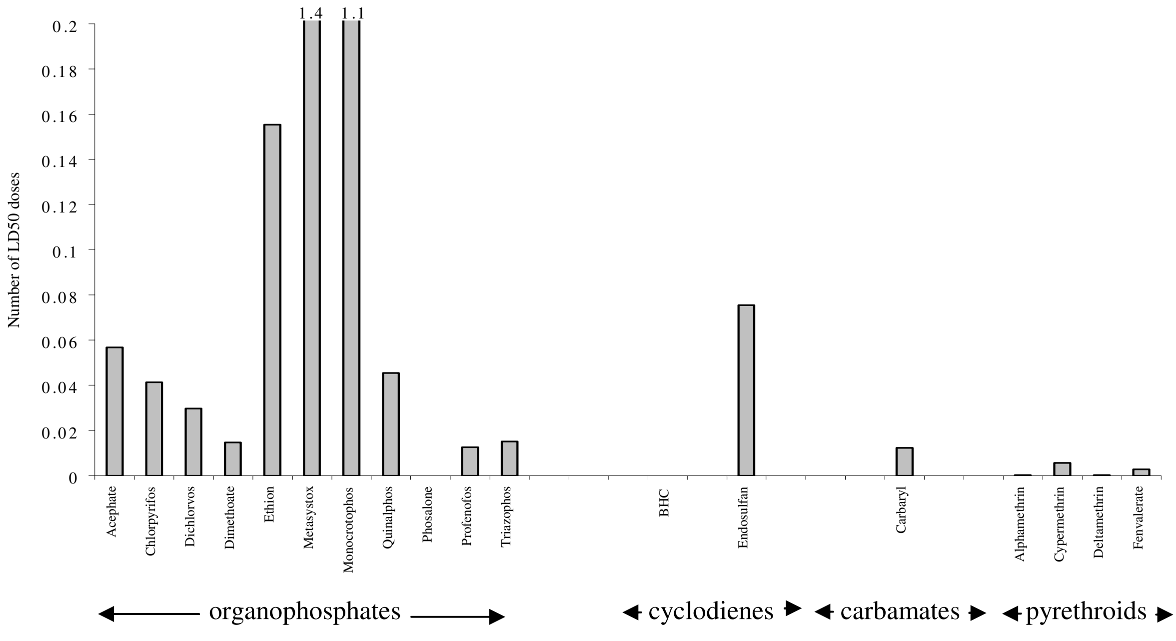


Fig. 5: Number of human LD_{50} doses of insecticides applied in farmers fields in IPM/IRM 'best-bet' demonstrations in 1998-9 (four states).

Component technologies evaluated for pesticides and IRM on-station and on-farm.

Imidocloprid

Imidocloprid as a seed treatment at 5g/kg seed proved to be highly effective as a sucking pest control product (Wood *et al*., 1998) (project report) and Surulivelu et al. (1998) (international conference paper). Control of jassids and aphids is good for 40-60 days after planting, depending on the site. A secondary perceived benefit for farmers is that the crop grows more rapidly and has glossier, greener leaves. The effect disappears before harvest but is a major factor influencing farmer demand. This product as a seed treatment (not as the foliar 'Confidor' or the competing product acetamiprid) fits well into the IPM/IRM strategy, as it has no negative impact on beneficial insect numbers (other than through the removal of their prey), and is effective enough to delay the application of broad spectrum insecticides until early in the fruiting phase in most cases. It is, however, applied prophylactically, something that many IPM practitioners dislike, and, on its release in 1999 was priced so highly that it is probably only economic on high-value/low-density hybrid cotton.

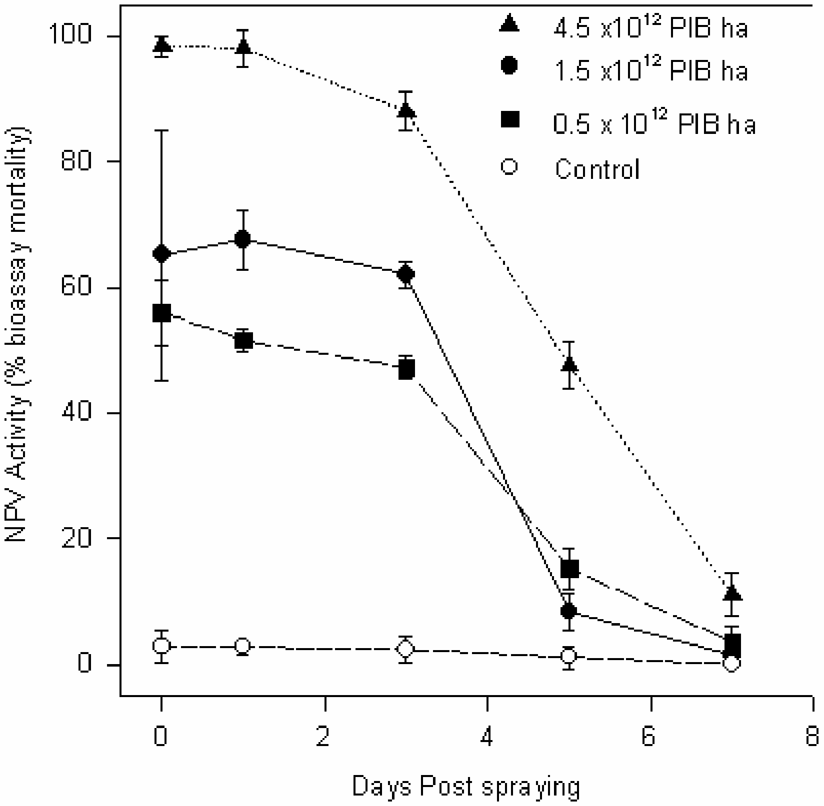
Spinosad

In collaboration with the manufacturers, the Nagpur laboratory provided the first report on the toxicity profile of spinosad against *H.armigera* and determined a baseline toxicity and diagnostic dose for future resistance monitoring (Kranthi *et al*., in press). Worryingly, there are suggestions of cross-resistance between spinosad and quinalphos. The materials share a similar target site, although the mechansism of action might have been expected to make cross-resistance unlikely. As this material is already registered in mixtures (to reduce the cost by reducing the level of a.i. of the spinosad) its field life may not be as long as might have been hoped.

The use of Helicoverpa nuclear polyhedrosis virus on cotton

Under a six month project amendment, Dr Rabindra's laboratory in the Entomology Department at PAU with assistance from Dr Grzywacz at NRI, investigated the persistence and efficacy of HNPV on cotton. Although increasing the application rate to 4.5×10^{12} as opposed to the TNAU recommended 3×10^{12} PIB/ha, or the CICR Nagpur rate of 1.5×10^{11} PBI/Ha, increased the initial kill of larvae to over 95%, there was practically no effect on the persistence, which is very short at 1-3 days under field conditions in cotton. Applications would have therefore to be very will targeted against the most susceptible younger instar larvae to have any major effect. This is a major drawback for HNPV use on cotton, which, in the opinion of the NRI team, should therefore not be routinely recommended for use on cotton until the factors relating the sunlight, cotton leaf chemistry and the viral particles infective ability, are technically resolved. For this reason, HNPV use was not actively promoted in this project.

Fig 6 Efficacy and persistence of HaNPV on cotton. Results from field trials Coimbatore, India 1997-98



Marigolds as a H.armigera egg trap crop
Marigolds are widely grown for temple and other religious ornaments. Earlier work at TNAU showed that ovipositing *H.armigera* females had a preference for flowering marigold over cotton. However, cage and field work in 1998 failed to replicate these results. It appears that only certain marigold cultivars are sufficiently attractive and that the flowing season of marigold is not long enough and does not tie in sufficiently well with that of cotton for the plantings to provide a reliable and significant economic benefit.

Cowpea as a nursery for predators
Cowpea is acceptable as a field edge crop in southern India. Cowpea matures before cotton and harbours an aphid species which does not survive on cotton. Predator numbers (esp coccinelid beetles, *Chrysopa carnea* lacewings and *Orius* heteropterans can build up on cowpea and move onto cotton when sucking pest populations are significantly higher during the early vegetative phase of growth. This IPM component was promoted in the South Indian demonstrations and received reasonable acceptance, although the benefit is not conspicuous to the farmer, who may be tempted to spray the cowpea as a secondary crop, destroying the beneficial insects.

Insecticide resistance test kits
A simple resistance detection method was developed at TNAU. This involved the dipping for a particular period, larvae of a certain size in proscribed dilutions of the pesticides which are supplied in the kit. Larvae are then allowed to feed on appropriate hosts and mortality

assessed at 24 and 48hrs. The kit has the advantages of being simple in conception and operation and cheap to make and disseminate. Its disadvantages are the somewhat crude nature of the test, which relies on care being taken in the time for which the larvae are immersed, and the necessary accuracy of the dilutions used. Perhaps more of a drawback is the need to maintain the larvae for 24-28 hrs. The kits were widely disseminated in Tamil Nadu and feedback is being sought.

Influence of cropping pattern on the natural rate of egg parasitism
Two seasons of work making extensive collections of *Helicoverpa* eggs from cotton planted in various mosaic patterns with sorghum and other crops, demonstrated that *Helicoverpa armigera* eggs in sorghum could act as a nursery for the major egg parasitoid, *Trichogramma chilonis. T.chilonis* from sorghum appear to move into cotton when eggs become unavailable in sorghum. They can parasitise c.30% of eggs in the early part of the cotton season, rising up to 90% of late season of *H.armigera* eggs in cotton. (Jadhav *et al*., 1999 submitted) It remains to be demonstrated that this level of egg parasitism has a major impact on *H.armigera* larval numbers feeding on cotton, but the work shows the potential for enhanced natural control through the manipulations of cropping patterns.

Production of insecticide resistance data from at least three locations on a limited scale in support of IRM/IPM component technology testing provision of baseline data in support of the area-wide approach to pest management.

Exploration of the pattern of resistance to the four major groups of chemistries (pyrethroids – cypermethrin and fenvalerate; organophosphates – quinalphos; chlorinated hydrocarbons – endosulfan and carbamates - methomyl) were undertaken routinely at all the centres. Depending on the methods used, results are reported both as the percentage of insects in a population surviving the discriminating dose of the insecticide which would kill virtually all fully susceptible insects (% resistance) and as 'resistance factors' (RFs). RFs are the number of doses required to kill 50% of susceptible insects (LD_{50} doses), which are required to kill resistant ones. Generalisations are risky but it might be said as a rule of thumb that resistance factors up to 10 are not very significant (incipient resistance). Resistance factors from 10-20 are of concern but unlikely to result in field failures. Resistance factors over 20 are likely to be problematic and when RFs rise into the hundreds, the usefulness of the chemical is clearly severely compromised. In general eggs and younger larvae are more susceptible to these conventional insecticides, probably in large part because they have not developed the full compliment of detoxifying enzymes present in older larvae.

The summarised average results for the whole cotton season are seen in fig. 7. These seasonal averages mask the within-season variation in insecticide resistance. This is shown for central India in fig. 8. Similar shapes of curves were obtained in other centres (see Podborer Newsletters 8 and 9 for details).

Pyrethroids:
Pyrethroids account for c.80% of all insecticides used on cotton, creating significant opportunities for resistance development. Pyrethroid resistance was high and stable in all centres (and especially in areas spraying pyrethroids more than 4 times per season). Taken across the country most *H.armigera* populations now show 80-95%% survival of the international discriminating doses of cypermethrin (0.1 µg) and fenvalerate (0.2 µg) (as representative pyrethroids). In the far south, where pyrethroid use has been more modest and

is falling due to action by regulators and lack of confidence in the material by farmers, resistance levels are significantly lower than further north. However, at a relatively micro level, resistance can vary dramatically over quite short distances (RF of 21 in Buldana in Andhra Pradesh, which is only 100 km form Akola which had an RF of 7,220. The explanation of the differences is likely to lie in the diapause and migration patterns of the moths at least as much as with the local spraying practices, with moths moving up from heavily sprayed coastal Andhra Pradesh to the Akola district.

In addition, a national survey of pyrethroid resistance in a range of lepidopteran pests of cotton was undertaken and is summarised in Kranthi *et al.,* (1999). Significant field resistance was found in 52 of the 54 strains tested and levels were generally higher than those reported for 1995 by Armes *et al.,* (1996) which in turn had risen strongly since 1987-8 (McCaffery *et al*., 1989). Resistance to deltamethrin was exceptionally high with resistance factors of 13,570 and 27,160 in two strains collected from central India in 1998. RFs were, however, under 100 in over 50% of the strains tested and some efficacy can still be obtained in most areas if sprays can be targeted against the most susceptible stages (eggs and young larvae). It must also be appreciated that pyrethroids retain much of their efficacy against pink, spotted and spiny bollworms and so are an important part of the farmers' armory, especially late in the season.

Organophosphates:

Organophosphate insecticides represent 70% of the Indian arable market for insecticides. Monocrotophos and quinalphos are two of the most widely used organophosphate insecticides in India, together constituting 75% of the total organophosphates used. Nearly 85% of the quinalphos and 68% of the monocrotophos is used on cotton alone (Anon, 1997). Resistance to the representative organophosphate (quinalphos) is stable at lower levels (20-30% resistance). This 1-29 fold resistance compared with susceptible strains, is nonetheless an increase over the figures of 1-9 fold recorded by Armes *et al*., (1994). These materials retain their usefulness but are unfortunately both widely toxic to non-target arthropods and have a relatively high mammalian toxicity (Iyengar and Russell 1999) in addition to being more expensive than the synthetic pyrethroids.

Cyclodiene

The only commonly used cyclodiene is endosulfan. Endosulfan is used partly because of its broad spectrum efficacy (against aphids and other sucking pests as well as other boll and leafworms) and partly because it is promoted as being relatively 'soft' on beneficial insects. Its impact on bees, predatory beetles and lacewings and on parasitic hymenopterans appears to be less than that of most pyrethroids or organophosphates. Resistance to endosulfan in India has generally been low at around 20-50% in most cotton areas, with 45-70% recorded in coastal Andhra Pradesh. Resistance factors from 2-28 were recorded in the 1996 national survey, indicating incipient resistance. Only one strain (Srkikalum) was considered fully susceptible. This has changed little since the late 19980s when McCaffery *et al*., (1989) recorded a maximum resistance factor of 13. However, Armes et al., (1996) note that even resistance factors as low as 5-10 have been associated with control failures and the RF of 13 in Guntur was apparently sufficient to render the chemical ineffective (McCaffery et al., 1989)

Resistance nationally is currently moderate at 30-45% depending on the season and site. Like the organophosphates, resistance to endosulfan rises during the spraying season and declines again before the next season (fig. 8 and Kranthi *et al*., 1998). It seems that these two groups of chemistries are cross-resisted, and that the resistance is somewhat unstable indicating that there is some disadvantage to being insecticide resistant in the absence of spraying pressure. This has implications for the management of these chemistries.

Carbamate
Methomyl is the only commonly used carbamate in India. Methomyl resistance was monitored at all sites except Tamil Nadu (where it is hardly used). Resistance levels of 2-38 fold were reported by Armes *et al.,* (1996) with the highest level in Guntur (coastal Andhra Pradesh) at 162 fold. Resistance in the current study was 1-22 fold, with higher levels in the coastal belt of Andhra Pradesh and some parts of central India. As with endosulfan and the organophosphates, resistance gradually rose over the spraying season (30-40% resistance in October but 69% in February in south central India). Resistance appears to be gradually on the rise with recent increases in the use of this chemical for *H.armigera* control.

Bacillus thuringiensis resistance
A baseline study of *Bt* susceptibility to be undertaken before the widespread introduction of *Bt* transgenics. This was carried out using a diet-incorporation assay with larvae from Bangalore, Hyderabad, Delhi, Coimbatore, Guntur, Varanasi and Nagpur. LD50s varied between 63 and 110ng/larvae compared to a susceptible baseline of 54-60ng/larvae. This suggests that there is currently no significant resistance to *Bt* in India (K.Kranthi unpublished data). Resistance factors of 35-40 fold have, however, been generated through laboratory selection over six generations (K.Kranthi pers. comm.) and cross resistance to various Cry toxins demonstrated.

Resistance in other cotton pests
Studies were undertaken at a range of sites across India at the Nagpur and ICRISAT laboratories.

Pink bollworm *(Pectinophora gossypiella)*
Limited data from south and central India suggests a high resistance to methomyl and quinalphos while only two (of 15) strains tested were resistant to monocrotophos. These resistant strains were from north India where pink bollworm occurs earlier in the season and is therefore more likely to be affected by monocrotophos applied for sucking pest control. Methomyl and quinalphos show cross-resistance.

Spotted bollworm (*Earias vitella*)
Like pink bollworm, the spotted bollworm is still susceptible to pyrethroids. Methomyl is still effective in most parts of the country. There is some resistance to monocrotophos and quinalphos, particularly further north and there is evidence of cross resistance between these two chemicals.

Leafworm (*Spodoptera litura*)
Pyrethroids are still effective for the control of leafworm. *S.litura* is susceptible to methomyl in all the strains tested except three from Andhra Pradesh. However, both monocrotophos and quinalphos resistance are widespread.

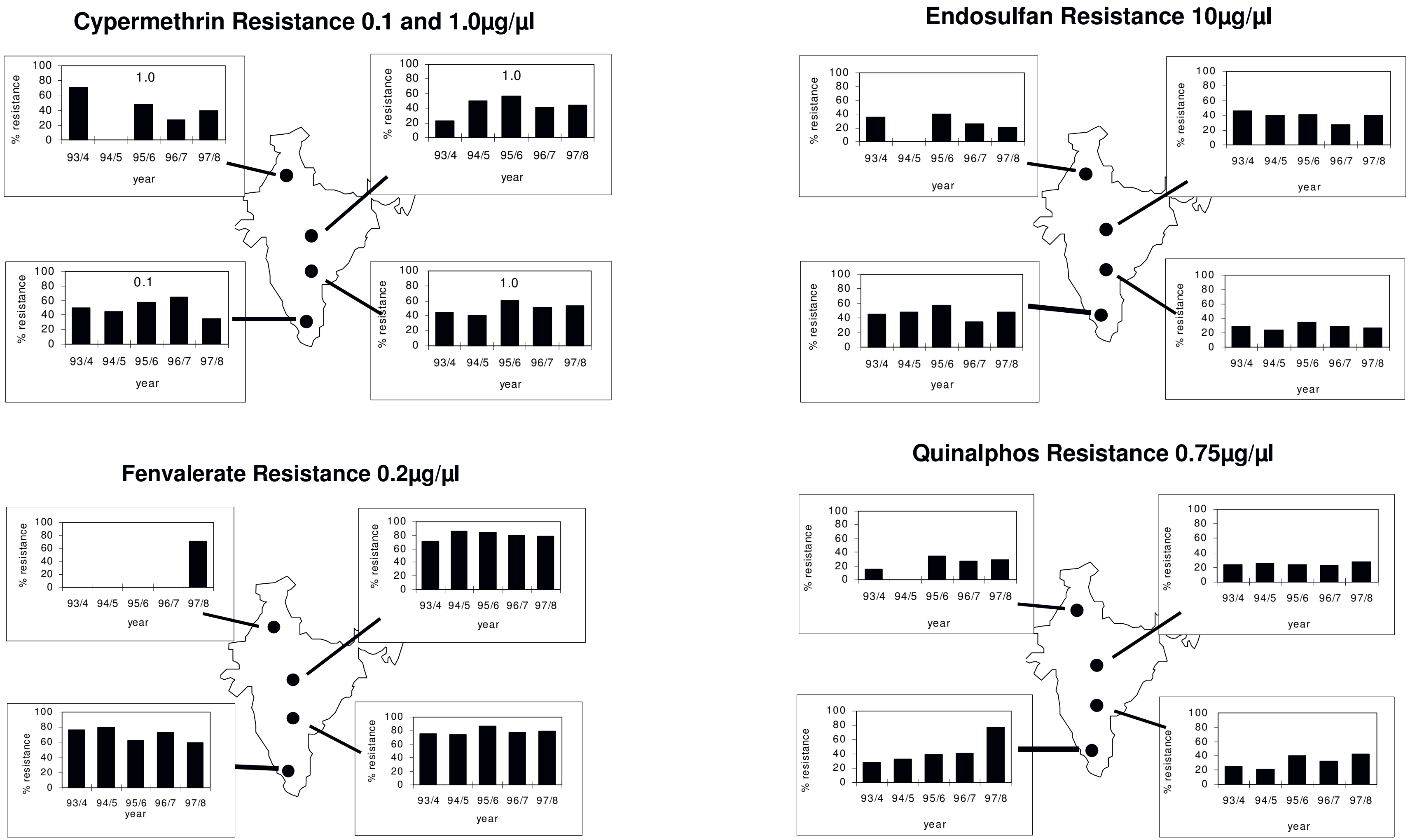
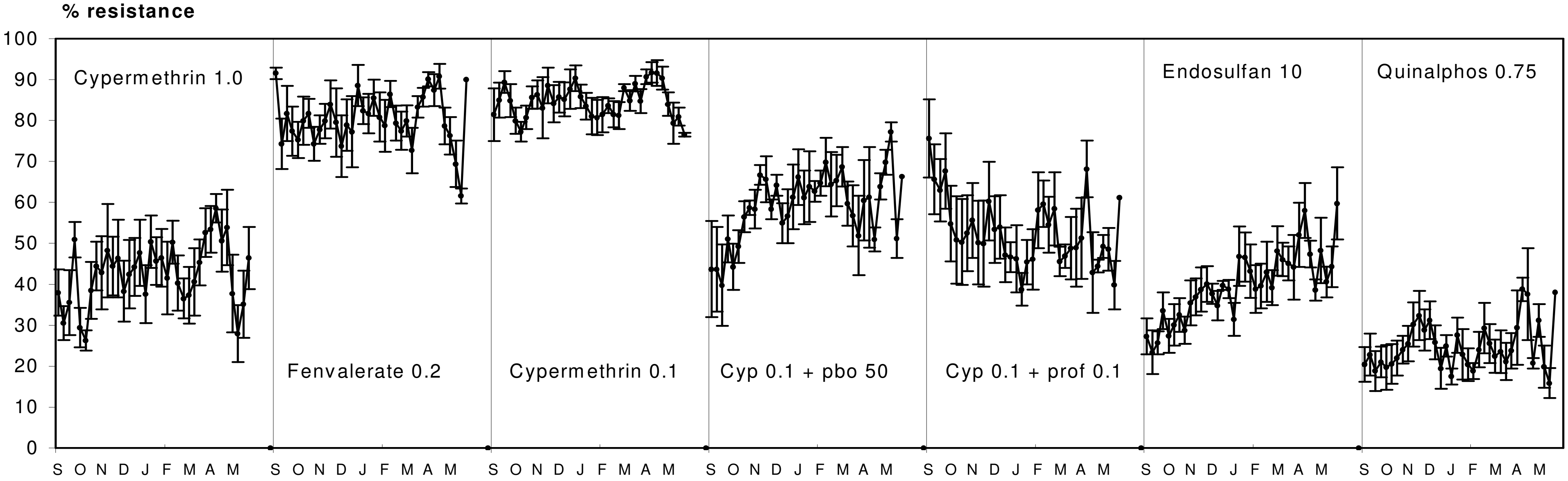


Fig.7: Percentage survival at a discriminating dose which would kill 95% of susceptible insects. (0.1µg/µl is the international discriminating dose for cypermethrin, but other than in South India, survival is so high that 1.0µg was used)

Figure 8: Seasonal (September to May) average of six years (1993-99) insecticide resistance monitoring data from Central India



Whitefly (*Bemisia tabaci*)
Detailed work, using leaf-dip assays has been carried out only on populations from Andhra Pradesh and the Punjab in 1997-1998. Resistance is significant to cypermethrin, and to acephate and monocrotophos. The populations are, however, still susceptible to chlorpyrifos, profenofos, triazophos, endosulfan and to the neonicotonyl – imidocloprid (D.Singh (1999), PAU and D.Jadhav, ICRISAT unpublished data).

Table 7 summarises the currently available information for cotton pests. There is, however, a great deal of variation between areas, seasons and within seasons at individual sites.

Table 7: Generalised scheme of insecticide resistance levels in cotton pests in India using example insecticides (pyrethroids - cypermethrin and fenvalerate; organophosphates – monocrotophos, quinalphos, chlorpyrifos, profenofos, acephate, triazophos; carbamates – methomyl; cyclodienes – endosulfan; neonicotinyl - imidocloprid). North – mainly Punjab, Central – mainly Maharashtra and Andhra Pradesh, South – Tamil Nadu

Pest Species	Insecticide	North	Central	South
American bollworm	Pyrethroids	v.high	v.high	High
(H.armigera)	Quinalphos	Low	Low (high in Guntur)	Low
	Monocrotophos	Mod.	High	High
	Methomyl	Low/Mod.	Low/Mod.	Low/Mod.
	Endosulfan	Mod.	Mod.	Mod.
Pink bollworm	Pyrethroids	None	None	None
(P.gossypiella)	Quinalphos	Mod.	Mod.	Mod.
	Monocrotophos	Low	Low	Low
	Methomyl	Low	Mod.	Low
Spotted bollworm	Pyrethroids	None	None	None
(E. vitella)	Quinalphos	Mod.	None	-
	Monocrotophos	High	None	-
	Methomyl	High	None	-
Leafworm	Pyrethroids	Mod.	High	-
(S.litura)	Quinalphos	Mod./high	Mod./high	Mod.
	Monocrotophos	Mod.	High	Mod.
	Methomyl	None	Low	None
Whitefly	Cypermethrin	Mod./high.	Mod./high	-
(B.tabaci)	Fenvalerate	High	High	
	Quinalphos	-	None	-
	Acephate	Mod./high.	-	-
	Monocrotophos	Mod.	Mod.	-
	Profenofos	None	None	-
	Chlorpyrifos	None	None	-
	Triazophos	None	-	-
	Metasystox	-	Low	-
	Methomyl	Mod.	Mod.	-
	Endosulfan	None	None	
	Imidocloprid	-	None	-

* Low – detectable resistance but not sufficient to give rise to field control problems
Mod. - moderate resistance, insecticide still useful but compromised
High - resistance sufficiently severe to significantly impare usefulness

Determination of insecticide resistance mechanisms and cross-resistance to insecticides in *Helicoverpa armigera.*

Pyrethroids
In the majority of areas studied, resistance to pyrethroids was mediated though metabolic mechanisms. The combined evidence of synergism bioassays and in-vitro enzyme assays indicated that pyrethroid resistance in most parts of India is due to enhanced esterase and mono-oxygenase activity (Kranthi et al., 1997 and 1998). However, the relative contribution of the various metabolic mechanisms can vary over short periods in the same areas. Fig 9a and b show the effects of PBO as an oxidase enzyme inhibitor and profenophos as an esterase enzyme inhibitor on resistance to a standard pyrethroid (cypermethrin) in the Nagpur area. It can be seen that the importance of the two resistance mechanisms (and therefore the level of resistance inhibition by the two synergists) varies over the season. The importance of the each of the two mechanisms seems to oscillate out of phase. When one mechanism is important the other is less so. This phenomenon would repay further study as it makes the effect of any synergists added to chemicals by the manufacturer difficult to predict.

However, the fact that full suppression of pyrethroid resistance was never achieved in any of the strains suggests that the mechanism of metabolic detoxification (though the main resistance mechanism in most areas) is not the only one. Non-synergisable resistance was highest in the Guntur strains which are amongst the most heavily sprayed in the country. Work at CICR Nagpur would suggest that nerve insensitivity is the main component of non-synergisable resistance to pyrethroids. This has important resistance management implications as nerve insensitivity seems to carry only a very low fitness cost for the insect having it and therefore remains in the population, even in the absence of immediate selection pressure from spraying. It is important that a long term reduction in pyrethroid spraying pressure is achieved in these key areas where pyrethroid use in high, if this class of compounds is to retain any significant usefulness there.

Organophosphates/ Carbamates
Armes *et al*., (1996) point out that the difference between the resistance response of the phosphate organophosphates (monocrotophos, acephate, dimethoate, diclorvos) and the phosphorothionate organophosphates (quinalphis, profenophos, chlorpyrifos, triazophos and ethion) organophosphates is probably due to the fact that mixed function oxidases mediated resistance to phosphorothionate insecticides while that of the phosphate type is unaffected by oxidative inhibitors. Both OPs and carbamates prevent the breakdown of acetylcholine at the post-synaptic membrane by inhibition of acetyl cholinesterase, thus promoting over-stimulation of the nervous system. Mutations with a form of Ache insensitive to inhibition have been found in *H.virescens* but target site resistance has not yet been demonstrated in *H.armigera*. Esterase mediated hydrolysis, or possibly sequestration, seem likely to be the most important mechanisms in Indian populations and to be responsible for the cross resistance of OPs and carbamates. However, P450 mono-oxygenases may also play a role (McCaffery 1999).

Methomyl is not a particularly effective bollworm chemical. High carbamate resistance frequency values are associated with high pyrethroid resistance frequency values suggesting a measure of cross resistance. This is given some support from the fact that resistance to methomyl was present almost from its first introduction to the country (Armes *at al*., 1996). Thiodicarb has been used extensively in Pakistan for a number of years with very little resistance development (Ahmad *et al*., 1998). It should perhaps be tried again in India although its mammalian toxicity profile is against it.

Figure 9a: **Effect of the addition of 50µg of piperonyl butoxide on oxidase mediated resisitance to cypermethrin in *Helicoverpa armigera* from the Nagpur area (compare with fig. 8 – cypermethrin 0.1µg).**

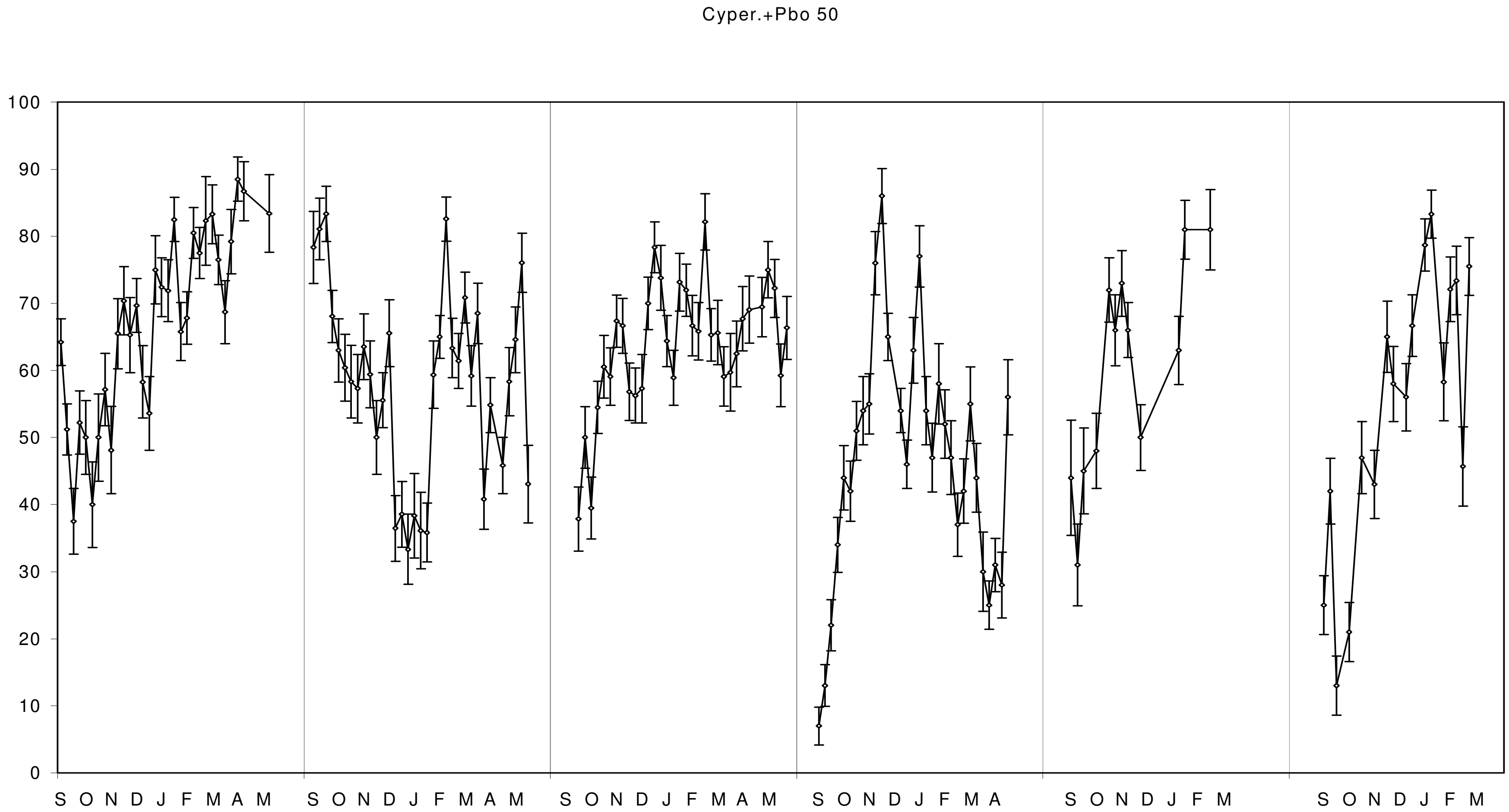
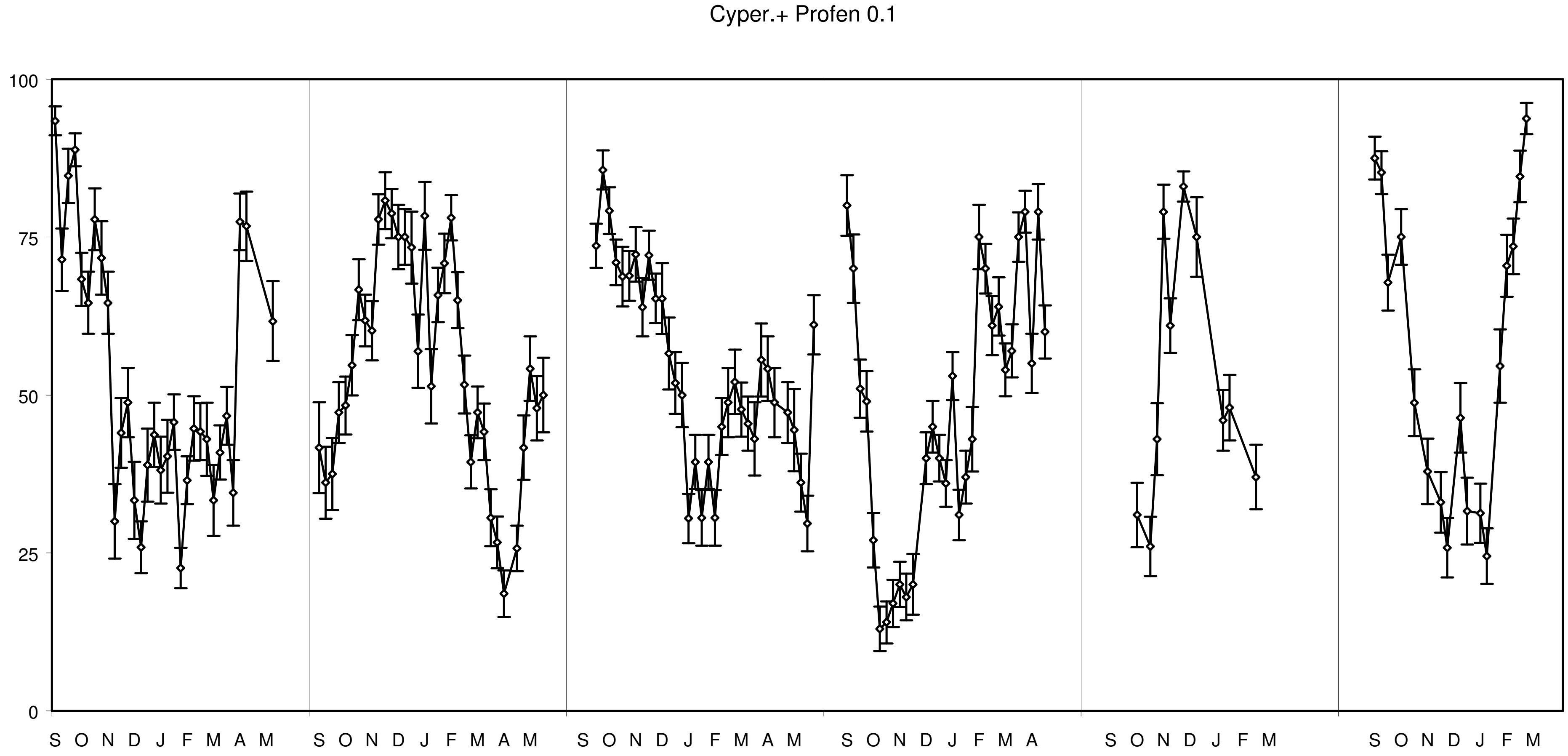


Figure 9b: Effect of the addition of 0.1µg of profenophos on esterase mediated resitance to cypermethrin in *Helicoverpa armigera* from the Nagpur area (compare with fig. 8 – cypermethrin 0.1µg).



Cyclodienes
Resistance to endosulfan has been regarded as due to the development of insensitive forms of the GABA gated chloride ion channel receptor complex, but this has not been demonstrated from India. The Nagpur laboratory havs been able to show a role for monooxygenases in the activation of endosulfan toxicity. As mentioned above, patterns of co-variation of resistance levels to endosulfan and quinalphos suggest some measure of cross resistance between the two groups.

The use of Pyrethroid/ Organophosphate mixtures

The use of registered and unofficial tank-mixes of insecticides is growing across Asia. Where more than one species of insect has to be controlled, this may sometimes save labour. However, the spurious chemical and resistance situation has resulted in the use of mixtures of insecticides from two or more chemical classes for the control of single species of bollworm, whiteflies or other pests, often with each chemical at the full recommended rate. In general, the scientific results do not support this expensive practice. Most mixtures are no more effective than the most effective component of the mix and many mixtures are antogonistic rather than synergistic.

However, there is a major exception to this generality. Monocrotophos (and acephate, dimethoate, dichlorvos etc) belongs to the phosphate group of organophasphates while quinalphos (and prophenophos, chlorpyrifos, triazophos and ethion) belong to the phosphorothioate group. This is significant, as the phosphorothioate group of OPs are strong estesase enzyme inhibitors. As much of the metabolic resistance to pyrethroids throughout Inida is esterase mediated, OPs of this group should therefore act as effective synergists of pyrethroids i.e. mixing a pyrethroid (which is resisted by this mechanism) with a phosphorothioate OP, will restore that part of the pyrethroid efficacy which was undermined by enhanced esterase production in the *H.armigera* caterpillars.

Laboratory trials demonstrated the practical importance of this. There are potential undesirable consequences of using such mixtures. In particular resistance may develop more rapidly to both components of the mixture. However, ethion is not, on its own, an effective bollworm chemical. Mixing this with, for example, cypermethrin or fenvalerate, gives a much enhanced performance of the pyrethroid without putting pressure on an otherwise useful OP. In north India in particular, the use of such mixes (especially cypermethrin/ethion) is growing rapidly. The problem is to restrict the release of commercial mixtures to only those mixtures showing genuine synergism. Registration of mixtures, previously frowned upon, has commenced in India, with six major mixtures released recently.

The wisdom of promoting even effective mixtures is hotly debated. One school of thought believes that not only will the resistance position be worsened, but farmers, seeing the promotion of certain mixtures, will be encouraged to make all sorts of ineffective mixtures themselves. It is also the case that the death rate of farm workers entering the hospitals with symptoms of poisoning from mixes sprays is far higher than those poisoned with only single ingredients (an antidote problem). The other school, currently in the ascendancy, believes that farmers are tank-mixing anyway, and that it would be better to supply genuinely effective mixtures in order to discourage random empirical combinations.

The development of non-insecticidal synergists for resisted pyrethroids.

As discused above, the use of certain organophosphates can synergise esterase mediated pyrethroid resistance. It is also desirable to find synergists for the other main metabolic resistance mechanism, increased production of mixed function oxidases (MFOs)

The project laboratories at Tamil Nadu Agricultural University had assessed a number of natural products (under project R5745CB) and chose for further study Pongami oil, a natural vegetable oil from the widely planted tree, *Pongamia glabra.* Pongamia oil acts as a synergist of pyrethroids where the resistance is mainly mediated through increased activity of mixed function oxidases. The efficacy of the oil was compared for efficacy against the standard industrial oxidase inhibitors piperonyl butoxide (PBO) and propargyloxy phthalimide. Pongamia oil suppressed cypermethirn resistance by 70% (as against 50% for PBO), and fenvalerate resistance by 80% (78% for PBO) (Regupathy *et al*., 1999). The pongamia tree is widely planted and the oil prepared using simple local technologies for other purposes. Preliminary analyses suggest that the oil could provide an economically attractive synergist and TNAU is pursuing its commercialisation.

A new synergist was discovered in the project laboratories at Nagpur. Xanthotoxin (8-methoxypsoralen), a naturally occurring botanical derivative, was found to enhance the toxicity of the synthetic pyrethroid, cypermethrin by 25 to 46 fold when used at 4 and 8 ug/larva respectively, in a pyrethroid resistant field strain of *Helicoverpa armigera* (Hubner). In comparison, PBO synergised cypermethrin up to 16 fold with 50 µg/larva. Xanthotoxin was found to inhibit *p*-nitroanisole-O-demethylase activity of fifth instar larvae in a dose dependent manner with an I_{50} (50% inhibition) of 16.86 µM. It did not induce any changes in the cytochrome p450 spectrum. The results strongly suggest the possibility of using of xanthotoxin or its analogues as pyrethroid synergists to manage resistant *Helicoverpa armigera.* A patent application has been submitted to ICAR.

Development of pyrethroid resistance detection kit

A pyrethroid resistance detection kit was developed in the project laboratory at CICR Nagpur, to enable the detection and determination of resistance frequency in field strains of *Helicoverpa armigera*. The kit which is based on the detection of the presence of resistance associated unique esterase isozymes on nitrocellulose filter membranes, can predict resistance frequencies at an accuracy of ± 10% for the third instar larval stage. The method is rapid and inexpensive. It has been tested for field populations and is suitable for use by field extension staff**.** Its further development and commercialisation is being supported from a Common Fund for Commodities project (2000-2004), being run by the same team (see below). Any patents will be held by ICAR on behalf of the Common Fund for Commodities and used in such a way as to benefit small-scale farmers globally.

'Centre of excellence' in insecticide resistance mechanisms and bioassay technologies supported. Transfer of nerve insensitivity equipment and expertise to at least one Indian NARS to aid understanding of resistance mechanisms in major lepidopteran pests.

As reported above, with the help of Dr Alan McCaffery of Reading University, a set of nerve insensitivity equipment was purchased, installed at CICR Nagpur, and appropriate training provided. Dr Kranthi's laboratory is now probably the premier laboratory in Asia for insecticide resistance studies (particularly as the ICRISAT laboratory team has been disbanded following the end of the project). Dr Kranthi has produced a stream of high quality papers, reports and patentable discoveries in relation to insecticide resistance and has now written what will become the standard handbook of laboratory methods in this area. The CICR laboratory organised a practical insecticide resistance short course (project, ICAR and industry (50%) funded) at Nagpur from 27 March to 4 April 199. Participants were selected from the pesticide industry and academics applicants. This DFID supported laboratory is to be the leading Indian laboratory in the upcoming Common Fund for Commodities Asian project on insecticide use in *H.armigera* control. This will provide further equipment and staff support to strengthen the laboratory as a 'centre of excellence'.

Report on farmers' perceptions and cotton pest management practices, and on the socio-economic aspects affecting adoption of new management technologies.

Dr Elangovan of Tamil Nadu Agricultural University and Dr Overfield of NRI carried out an assessment of the factors influencing uptake of the project recommendations in Tamil Nadu, Maharashtra, Andhra Pradesh (south India, dry land cotton project) and the Punjab (northern, irrigated cotton project) (Elangovan *et al.,* 1999 and Elangovan and Overfield, 1999).

Specifically the aims were to analyse the level and determinants of adoption of the IPM/IRM system being promoted, and to examine the sustainability of the technology. The study, at the end of the 1998 cotton season, used five randomly selected farmers from each of the nine project villages in Maharashtra, 15 farmers from each of the three project villages in Andhra Pradesh and 30 farmers from the Tamil Nadu village, for data collection by interview fifteen of the interviewed farmers from each of Andhra Pradesh and Tamil Nadu were in their second project season.

The measured determinants of adoption in the econometric model (see Elangovan and Overfield, 1999 for details) varied from site to site but included:

- family size;
- highest education;
- highest experience;
- owned land;
- leased-in land;
- leased-out land;
- other income;
- radio and TV extension contacts;
- government extension officer contact;
- company sales representative contacts;
- advice from fellow farmers.

Amongst the Maharashtra farmers, adoption of all 14 main technical components of the cotton IPM strategy lay between 77% and 100%. The model of factors determining adoption explained only 56% of the variability but statistically significant determinants of adoption (summary list below) were listening to radio messages and the lack of non-farm income. (Elangovan *et al*., (1999)

Adoption of the technical IPM/IRM components of the programme in Andhra Pradesh lay between 60 and 100% and the modelled determinants of adoption explained 81% of the variation. Significant determinants of adoption were advice provided by television, educational level and the lack of utilisation of leased-in land.

With the farmers in Palani, Tamil Nadu, adoption was between 87% and 100%, presumably occasioned by the fact that the same project village was the focus of the work in 1997 also. The modelled determinants of adoption explained 90% of the uptake pattern even though no single determining factor was significantly positively correlated with adoption. Both the length of the farmer's cotton growing experience and the provision of advice by pesticide dealers were negatively correlated with successful adoption.

In the northern sister project, where pest pressure was much greater, knowledge of the different major pests and their life stages and appropriate application of this knowledge, was present in 97% of the sample, as was an appreciation that single sprays and not mixtures should be used wherever possible. The importance of agronomic practices such as the need for thinning (c.80% of farmers), the importance of judicious use of fertiliser and irrigation (67% of farmers) were well understood. However, the details of the insect sampling procedure as a prerequisite for insecticide interventions were less well internalised by farmers with between 36% and 53% appreciation and adoption depending on the particular component being explored. Awareness of the details of the CLCuV recommendations was even poorer. Clearly a greater extension effort is required. This was somewhat disappointing, though perhaps not surprising, given that this was only the first year of technology extension for the very large number of farmers in these villages

Of the determinants, farmer education level (and more importantly, the general education level in the whole family) seems clearly linked with adoption and it is apparent that radio and TV broadcasts can be an effective way to disseminate information. The advice of insecticide sales representatives, correlated positively with adoption of the project practices in the Punjab but not further south, vindicating the effort expended in meeting with insecticide dealer networks and individual dealers in the Punjab in an effort to explain the principles and benefits (including to the dealers) of rational pesticide management. This component warrants attention in all IPM/IRM programmes. Unexpectedly, the area of land owned was generally negatively correlated with adoption, possibly because those with larger commercial farms did not themselves carry out the crop management practices. It is clearly important to influence the operatives as well as the farm owners.

Farmers said that they would continue to apply the principles they had learned in future years. The measure of positive farmer to farmer spread of information within the season supports this view. In the Maharashtra village cluster, where pest pressure was much lower than in the Punjab or other sites during 1998, adoption spread very rapidly from a little over a hundred farmers at the beginning of the season to around 1,600 by the end.

Scientific publications, bulletins and pest handbooks

The project results and conclusions were presented in nine journal articles and 24 conference and meeting papers. The ongoing work has been provided to the resistance reseach community though the Podborer Newsletter and to the farmers though a number of high-quality colour brochures in Tamil, Marati and Hindi as well as in English. These have been sold to farmers for a nominal sum to encourage their utilisation. The funds gained have been used to produce further printings and editions on a rolling basis (see publication list).

Use has been made of the Indian press for wider dissemination of the project objectives, both through newspaper articles (see list) and with radio announcements during the season. State television played a supportive role, particularly in Maharashtra.

6. Contribution of outputs

The outputs have successfully contributed to the Goal of the Production System *Impact of significant cotton pests minimised* by developing and validating sustainable methods to halt and reverse the problems which are threatening India's cotton production. This is very significant. If these practices were to be implemented on the c.8 mill ha of cotton in India, control of *H.armigera* and whitefly on their many other agricultural hosts would be greatly simplified for the 60 million livelihoods which depend on cotton production and processing in India. The project findings represent significant steps forward in the scientific understanding of resistance management based on the dynamics of its development and the physiological mechanisms involved. Moreover this knowledge was translated into recommendations for farmers which allowed pesticide use to be reduced, and where applications were necessary, to be used in a more considered and sustainable way. The hundreds of farmers who adopted the pest management recommendations were able to produce more profitable crops based on a pattern of pest management with greatly reduced environmental risk and with the pressure for further resistance development diminished. Undertaking this work on a village cluster basis has shown benefits in changing the attitudes of communities and so on the social pressure on individual farmers to spray. The enthusiasm of the farmers and those who have witnessed their success has infected decision makers and is leading to widespread support for the expansion of adoption of the pest management principles established by the project, which has demonstrated that with an understanding of the scientific principles, it is possible to break out of the spiral of increasing insecticide use by following simple guidelines.

Follow-up indicated and planned

a. ICAR has set up and is fully funding, an immediate continuation of the project work in the four states of the two sister IRM projects (Punjab, Maharashtra, Andhra Pradesh and Tamil Nadu) (1999-2002) and led from CICR, Nagpur. This project continues and expands on the village adoption demonstrations of the ‘best-bet’ practices, while gaining further information and refining recommendations.

b. The findings of the project fired the imagination of the policy makers in India, and to capitalise, the CICR has had a proposal accepted by the Government of India to oversee and guide technology transfer, building on the DFID project model. It involves 500 villages in eight states, and focuses on the 25 heaviest insecticide-using districts in India which between them are responsible for 82% of the insecticide use on cotton. The plan involves mobilising a wide range of public and private sector bodies to create cotton IPM support centres in each district. These include the Agricultural Universities, ICAR institutions, State Departments of Agriculture, quangos such as the Cotton Corporation of India, MarkFed, IFCO and KRIBCO and the private sector chemical and seed companies. From these centres insecticide resistance levels will be monitored and appropriate pest management plans developed. Pest scouting will be organised at the village level and help will be provided obtaining quality inputs – certified seeds, fertilisers and quality insecticides. Concurrence has been obtained from the Union Agricultural Commissioner and additional financial support has been provided from the Cotton Corporation of India and 10 major insecticide and fertiliser companies.

The scale and diversity of the NARS system in India makes it difficult to maintain the momentum and direction of developed IPM systems in the national follow-on programmes described above. The DFID Crop Protection Programme has provided funds (1999-2000) to allow the NRI project team to promote the project outputs by supporting adoption of the technology; through training visits, attendance at meetings, production of farmer literature and the promotion of liaison between the programme partners.

c. A major new international *Helicoverpa armigera* pest management project in cotton funded by the Common Fund for Commodities (2000 – 2004) is being set up under the supervision of the International Cotton Advisory Committee. It is co-financed by the Indian Council for Agricultural Research , the Central Cotton Committee of Pakistan, the Ministry for Science and Technology in China and the chemical industry's International Insecticide Resistance Action Committee. It will expand the work carried out in the project to Pakistan, China and parts of Africa as well as maintaining the Indian nucleus of activity. The terms of reference of the new initiative within the four countries are to fill the knowledge gaps in relation to long-term sustainable use of pesticides and their mixtures, address the problem of insecticide resistance management, and to present and demonstrate the conclusions in a form directly, easily and reliably applicable by the small farmer. Support for the UK technical component of this work is being sought from the DFID Crop Protection Programme.

d. Through the World Bank Agricultural Technology Project, (NATP), approval has been obtained for the funding of a network of insecticide resistance laboratories in nine states, including support for all the previously DFID funded laboratories in the two projects (except ICRISAT). This work is still to commence for unclear reasons. However, limited resistance monitoring is continuing through the ICAR 'village adoption' programme mentioned above.

e. The Cotton Corporation of India (CCI) has very substantial funds for the support of IPM programmes but the current impact of this funding is minimal. Efforts are being made to re-orient this programme towards the provision of support for the training and support of local IPM agents to implement the programmes outlined above.

f. The EU is funding a six country Asian cotton farmer-field school IPM programme (FAO implemented) to train 90,000 cotton farmers from 1999-2004. Based on the current project, PAU will contribute to the programme for north India and the project pest control recommendations have been presented to the six countries for incorporation into the FFS curriculum.

7 Publications

Those marked with an asterisk were written with R6760 'A systems approach to sustainable insect pest management in irrigated cotton in India' which also ran from 1996 to 1999 and shared the same project UK staff and many of the objectives, though for irrigated, rather than dry-land cotton.

Journal Articles

*ELANGOVAN, P and OVERFIELD,D. (in prep). Dimensions of adoption and sustainability in the use of insecticide resistance management techniques in different parts of India.

*IYENGAR, L. and RUSSELL, D.A. (submitted 1999). Implications for non-target organisms of implementing an insecticide resistance management strategy for the control of cotton pests in India. *Ecotoxicology*.

JADHAV, D.R., RUSSELL, D.A. and ARMES, N.J. (submitted 1999) Impact of sorghum on natural parasitism of *Helicoverpa armigera* (Hubner) by *Trichogramma chilonis* Ishii in cotton in India. *Biocontrol Science and Technology.*

KRANTHI, K.R (submitted 1998) Cypermethrin synergism by Xanthotoxin and its in vitro effects on mono-oxygenases of Helicoverpa armigera. *Crop Protection.*

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KRANTHI, R.K., JADHAV, D., WANJARI, R., KRANTHI, S. and RUSSELL, D.A. (submitted 1999). Pyrethroid resistance and mechanisms in field strains of *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae). *Journal of Economic Entomology*.

*OVERFIELD, D. and MALHAN, R.S. (1999 submitted) The green revolution, changing farming systems and declining cotton yields in the Indian Punjab. *Agriculture, Ecosystems and Environment.*

Conference Presentations

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KRANTHI, K.R. Resistance, resurgence and cocktails.(1998) Proceeding of the National Level Discussion on '*Critical issues of IPM in the changing agricultural scenario in India'*, Ludhiana November 28-29 1998 Punjab Agricultural University, Jan 1999.

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RUSSELL, D.A. (1998) Resistance in *Helicoverpa armigera* in India. *Proceedings of the final meeting of the Heliothis Network Research Project* (ICAR), PAU Ludhiana, June 24-25, 1998.

Newsletters

Podborer Newsletter **8** (Nov 1997) and **9** (Oct 1998) documenting the patterns of insecticide resistance in *H.armigera* and *B.tabaci* across India and the progress of the field demonstrations of IRM. CICR Nagpur.

Training manuals and brochures

CICR (1998). Insect Pest Control. Colour brochure in English, Marati, Hindi and Tamil versions, detailing cotton pests and their management – farmer handbook of project practices for each major cotton area. Two editions. August (1998) 2,000 copies (sold out) and Dec (1998), 2,000, 3rd edn. in press. CICR, Nagpur

CICR (1999) Sustainable cotton pest management through IRM. CICR Technical bulletin No 1/1999.

COOPER, J., SINGH, J. and KRANTHI, K. (1998) Insecticide use in cotton. Training of trainers manual covering all aspects of insecticide use in irrigated cotton. CICR Nagpur April 1998.

KRANTHI, K.R. and RUSSELL, D.A. (In Press). Techniques in insecticide resistance research and management. *ICRISAT Technical Manual No 4* (an ICRISAT/ICAR/DFID production)

Project Reports
In addition to the quarterly and annual centre reports used to compile the project reports.

ALI, ARIF MOHAMMED (1997) Socio-economic study of on-farm farmer participatory area-wide demonstrations for the management of insecticide resistant cotton pests in southern India 1997-1998 pp 105.

ELANGOVAN, P. (1998) Dimensions of adoption and sustainability in the usage of insecticide management techniques in different parts of India. 25pp.

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OTHER DISSEMINATION OUTPUTS

Farmers field days:
Six farmers' field days were held, at the close of the 1997 and 1998 seasons in each of the three states. These field days provided a platform for the local farmers to explore the benefits and any problems experienced in operating the projects. Large numbers of farmers from the surrounding villages attended, generating requests for project extension to these areas in the following season.

Insecticide dealers meeting
Wardha - April 1998. 400 dealers attended to hear about the project programme and discuss its implications in respect of pesticide sales and dealer advice. C.100 operating close to the project areas became directly involved.

***Training courses in insecticide application and safety*:**
Maharashtra :
Koradi - 19 Aug. 1977 50 farmers
Wardha - 18-20 Aug 1998 - training of trainers - 20 IPM extension personnel plus 8 NGO staff

Andhra Pradesh:
Maddikattu, Tangapally, Sankepally and Parveda - Aug 26-29 - 200 farmers

Tamil Nadu:
Kalipatti - Oct. 1998 - IPM extension agents, 50 farmers, TNAU research associates.

Workshops and meetings organised:
Discussion meeting: Present scenario on insecticide resistance in Helicoverpa *and pesticide application technology*, (with Central Tobacco Research Institute, Rajamundry and IRAC India) Secunderabad 20 Dec 1997 - for the pesticide industry and academics (22 participants)

Insecticide Resistance - a short course. Central Institute for Cotton Research, Nagpur, 27 March - 4 April 1998. (With Indian Council for Agricultural Research) - a practical course in the techniques of resistance measurement, monitoring and mechanisms research. (limited to 18 participants from industry, academic and government technicians) (50% industry funded).

Television:
EENADU Television (Telagu channel for Andhra Pradesh) (22 Dec 1997) 3 minute report on success of the 1997 farmers insecticide resistant pest management programme

EENADU Television (Telagu channel for Andhra Pradesh) (9 Nov 1998) 5 minute feature in prime time on the success of farmer participatory work, focusing on farmer and village leader interviews.

Newspapers:

THE HITIVADA *-26 Nov 1996* - Biotechnology for sustainable agriculture (Maharashtra - English language)

LOKMAT TIMES - 25 Nov 1996 - Cotton producers biotechnology group meeting (Maharashtra - Marati)

THE HINDU 3 Feb (1998) IRM technique to keep cotton pests at bay. (National English language paper)

NEW INDIA 26 Nov (1996) International cotton biotechnology meeting from today (Maharashtra - Hindi)

LOKMAT TIMES 26 Nov (1996) Hi-tech will boost cotton production: Dr Russell (English Maharashtra)

HITAVADA 26 Nov (1996) Insect resistant varieties of cotton developed. (Maharashtra - English)

ANDHRA PRADESH TIMES 17 Dec (1997) - Farmers Day (Project farmers field day) (AP English)

DECAN CHRONICLE 17 Dec (1997) ICRISAT to demonstrate pesticide use (Project village programme launched) (AP - English)

NEWSTIME 22 Dec (1997) Ryots warned against excessive use of pesticide (Andhra Pradesh - English)

HINDU 22 Dec (1997) Excessive use of pesticide will harm crop (English, Andhra Pradesh)

LOKMAT TIMES 28 March (1998) CICR course on Insecticide Resistance inaugurated (Maharashta, English language)

INDIAN EXPRESS 19 Aug (1998) Use pesticides scientifically, farmers told.

INDIAN EXPRESS Nov 11 (1998) Cottoning on to IRM project pays dividends (Leading English paper in Maharashtra - syndicated nationally to the 22 regional editions)

EENADU 14 Nov (1998) ICRISAT's advice reduces farmers' expenses by half (Telagu paper in Andhra Pradesh)

ANDHRA JOTI 14 November (1997) More yields for cotton farmers (farmers field day report) (Andhra Pradeah- Telagu)

INDIAN EXPRESS 28 March (1998) Need stressed to fight American bollworm - CICR course on insecticide resistance opens. (Maharashtra - English)

HITAVADA 28 March (1998) Scientists to help cotton farmers check pests. (Maharashtra - English)

EXPRESS NEWS SERVICE 12 Feb (1998) Pesticide industry must help in IPM implementation: Kairon (project resistance course inauguration) (Maharashtra – English)

INDIAN EXPRESS 16 May (1998) CICR to conduct effective cotton pest management trials in Wardha villages. (Maharashtra - English)

FINANCIAL TIMES (UK) 9 June (1998) Pest devastate Indian cotton crop - crude use of chemicals has exacerbated the effects of bad weather.

VAARTHA 14 Nov (1998) ICRISAT's advice helps control cotton pests (AP - Telagu)

THE HINDU Jan 12 (1999) Farm Institute helps cotton growers reap richer yield. (Tamil Nadu project results) (National-English)

DECAN CHRONICLE 17 Dec (1997) ICRISAT to demonstrate pesticide use (Andhra Pradesh - English)

THE HINDU Dec 21 (1997) ICRISAT, UK agency develop pesticide for cotton (Andhra Pradesh - English)

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ANNEX 1: PROJECT RECOMMENDATIONS FOR THE MANAGEMENT OF INDIAN COTTON (North and Centre/South)

IRM Recommendations for North India

(Minor changes may be required based on regional requirements)

MARCH-APRIL

Pre-sowing operations

Selection of cultivars for North India

Early maturing: F-846, F-1378, LH-1556, F-2054, H-1098
Recommended hybrids: Omshankar, Fateh, Dhanalaxmi.
For CLCV prone areas: RS-875, LHH-144, LRK-516, LRA-5166, All desi types (LD 327, HD-107, LD-491)
*Resistance /tolerance to ja*ssids : Bikaneri Narma, H-777, RS-875, RST-9, F-5-5, Fateh.

- Avoid growing American cotton in orchards
- Avoid growing tur, moong and bhendi in and around cotton field as these harbour insect pests.
- Immediately after the season allow animal grazing in fields and ensure timely removal and destruction of cotton stubbles, followed by deep ploughing to expose the carry-over population of bollworms.
- Do not stack cotton stalks near fields.
- Crushing of cotton seeds should be completed by end of April, or fumigate seeds with celphos @ 3g/cubic meter.
- Hybrids must be grown in medium –deep soils having good drainage
- Early sowing on ridges and furrows, especially in areas with drip facility, could be adopted.
- Application of weedicide Stomp 30EC or Basalin @45EC 2.5 lt/ha and harrow immediately to prevent degradation.
- Harrowing must be done twice after pre-monsoon showers and field should be levelled.
- Prepare a good seed bed to ensure good plant stand
- Grow only *arboreum* cotton in CLCV hot-spot areas
- Only recommended varieties/hybrids from reliable sources must be procured.
- Apply 10-15 cartloads of well decomposed compost or FYM /ha before sowing.
- Destroy weeds such as Sida, Abutilon and Xanthium before sowing to reduce CLCuV incidence.
- Delint the seed with 100 ml sulphuric acid /kg seed for two minutes, wash with water and soak for two minutes in sodium bicarbonate (5g/ltr water)
- Treat seeds with Ceresan wet or Agallol @ 1 g/ltr water.
- Treat seeds with Captan or carbendazim @ 2g/kg.
- Seed treatment (Carbosulfan 20g/ Kg seed., Carbofuran 25g/Kg seed) also helps in delaying the first spray (Imidacloprid 7g/Kg seed was found useful for hybrids in protecting the crop against jassids up to 40-60 days).

MAY

Sowing operations

- Grow sucking pest tolerant genotypes. It helps in delaying the first spray, thus conserving the initial build-up of natural enemies. If Jassid tolerant cultivars are treated with imidacloprid or carbosulfan, it is possible to avoid spraying for at least two months.
- Sow at a row spacing of 67.5 cm with 30 cm plant-plant spacing or preferably wider for varieties and 75cm for hybrids.
- Apply Urea @ 78 kg /ha for varieties and 156 kg/ha for hybrids at the time of sowing. Avoid excess urea as this encourages pest attack.
- Sowing must be completed by the third week of May.

JUNE-JULY

Vegetative phase

- Gap filling must be completed within 10 days after sowing
- Thinning should be done within 20 days after sowing.
- Apply 100 kg super phosphate and Urea @ 39 kg /ha for varieties and 78 kg/ha for hybrids one month after sowing.
- Repeat application of 100 kg super phosphate and Urea (@ 39 kg /ha for varieties and 78 kg/ha for hybrids) two months after sowing.
- First hoeing can be done 30-40 days after sowing followed by second after 15-20 days.
- Off-season hosts must be discouraged. Weeds such as Sida sp., Abutilon sp and Xanthium sp. must be uprooted to prevent initial build-up of spotted bollworm, whitefly and CLCV.
- Spotted bollworm can cause damage to growing points.
- Set up pheromone traps @ 5/ha for pink bollworm. Eight moths /trap/night for three consecutive nights is the action threshold.

JULY-AUGUST

Peak vegetative phase

- Jassids cause maximum damage during this time
- Whitefly starts being problematic from July to September
- Pink bollworm starts by August and damages till October.
- Do not use broad spectrum insecticides such as monocrotophos, as it destroys build-up of natural enemy populations.
- Do not use any insecticide within three months of sowing. Except Endosulfan (as emergency option against jassids at 2/leaf) or pyrethroids.
- Use of endosulfan should be encouraged only as early season spray (resistance levels have been found to be invariably low early in the season), as it is relatively less toxic to natural enemies. Avoid use of broad spectrum organophosphates such as monocrotophos, acephate etc. especially as early season sprays as these strongly disrupt the natural enemy populations.
- Pyrethroids should be used only once. Synthetic pyrethroids either as over dose or repeated sprays lead to excessive whitefly flareup.
- Set up pheromone traps @ 5/ha for *H.armigera* to identify brood emergence.

SEPTEMBER-OCTOBER

Reproductive phase

- Do not spray pyrethroid during after second week of September.
- American bollworm causes maximum damage during this period.
- Consider egg based ETLs for Helicoverpa @ one egg/plant and use NPV 250 LE/ha (6 X 10^9 PIB's/LE)or Neem seed Kernel Extract 20-25 Kg seed/ha can be used as initial sprays. This helps in conservation of natural enemies.
- Resistance levels against certain organophosphate group of insecticides (Quinalphos, Chlorpyriphos & Profenophos) and carbamates such as methomyl have been found to be relatively lower in most populations tested. Hence, it is preferable to use these as effective larvicides during mid-season (Sept-Oct) based on ETLs when the situation warrants.
- Pyrethroid resistance is high in many parts of India. These can be effective on *Helicoverpa* only on younger larval stages or adults or if used along with synergists such as sesamum oil However, pyrethroids are still effective against spotted and pink bollworm. Hence pyrethroids can be used either as early season sprays to target spotted and pink bollworm *or Helicoverpa* moths and young larvae.
- Handpicking of larvae 2-3 days after insecticide sprays effectively eliminates any surviving population which can cause future resistance problems.
- Always use insecticides as need based applications as per threshold levels. The keys to obtain better result from the use of insecticides are
  Right timing- use insecticides only when the need arises
  right chemical- choose appropriate insecticide
  right dosage- use only recommended dose
  right method- use proper sprayers and spray methods.
- Always target younger stages of *Helicoverpa* as younger stages of resistant larvae are known to get killed at normal recommended doses.
- Rotation of chemical groups helps in preventing the build up of resistance against most insecticides, especially carbamates, organophosphates and endosulfan.

IRM Recommendations for Central and South India

(Minor changes may be required based on regional requirements)

APRIL-MAY

Pre-sowing operations

Selection of cultivars

Recommended hybrids: NHH-44, PKV HY-2, JK Hy-1, JK Hy-2, H-8, H-10, Ankur-651
Recommended varieties : LRA-5166, LRK-516, PKV-081
Desi types : AKH-4, AKH-8401

- Immediately after the season allow animal grazing in fields and ensure timely removal and destruction of cotton stubbles, followed by deep ploughing to expose the carry-over population of bollworms.
- Do not stack cotton stalks near fields.
- Hybrids must be grown in medium –deep soils having good drainage
- Early sowing on ridges and furrows, especially in areas with drip facility, could be adopted.

- Application of weedicide Stomp 30EC or Basalin @45EC 2.5 lt/ha and harrow immediately to prevent degradation.
- Harrowing must be done twice after pre-monsoon showers and field should be levelled.
- Prepare a good seed bed to ensure good plant stand
- Only recommended varieties/hybrids from reliable sources must be procured.
- Apply 10-15 cartloads of well decomposed compost or FYM /ha before sowing.
- Destroy weeds such as *Datura metal* and *Legascea mollis* near fields. These support Helicoverpa populations during off-season.
- Delint the seed with 100 ml sulphuric acid /kg seed for two minutes, wash with water and soak for two minutes in sodium bicarbonate (5g/ltr water)
- Treat seeds with Ceresan wet or Agallol @ 1 g/ltr water.
- Treat seeds with Captan or carbendazim @ 2g/kg.
- Seed treatment (Carbosulfan 20g/ Kg seed., Carbofuran 25g/Kg seed) also helps in delaying the first spray (Imidacloprid 7g/Kg seed was found useful for hybrids in protecting the crop against jassids upto 40-60 days).

JUNE

Sowing operation

- Grow sucking pest tolerant genotypes. It helps in delaying the first spray, thus conserving the initial build-up of natural enemies. If Jassid tolerant cultivars are treated with imidacloprid or carbosulfan, it is possible to avoid spraying for at least two months.
- Sowing can be done at a row spacing of 90 cm with 60 cm plant-plant spacing for hybrids, 60 x 30 cm for varieties and 45 x 20 for Desi cultivars..
- Apply 18:18:10 @ 250 kg/ha for hybrids and 170 kg/ha for varieties at the time of sowing. Avoid excess urea as this encourages more pest attack.
- Sowing must be completed by the first week of July

JULY-AUGUST

Vegetative phase

- Gap filling must be completed within 10 days after sowing
- Thinning should be done within 20 days after sowing.
- Apply 100 kg Urea 50 days after sowing.
- First hoeing can be done 30-40 days after sowing followed by second after 15-20 days.
- Off-season hosts must be discouraged. Weeds such as *Legascea mollis* and *Datura metel* must be uprooted to prevent initial build-up of *Helicoverpa armigera.*
- Spotted bollworm can cause damage to growing points, but does not cause economic losses.
- Jassids and Aphids cause maximum damage during these months. Populations of Lady bird beetles are also generally high and assist in reducing the pest load.
- Do not use broad spectrum insecticides such as monocrotophos, metasystox, acephate or any other insecticides belonging to the organophosphate group, as they strongly disrupt natural enemy populations.
- Do not use any insecticide against jassids or aphids within three months of sowing. Except Endosulfan (as emergency option against jassids at 2/leaf, and aphids 50/leaf).

- Avoidance of organophosphate insecticides for the first three months helps in build-up of entomophage populations such as *Chrysoperla, Campoletis chloridae, Microchilonis curvimaculatus,* Tachinids*, Apanteles*, Reduviid bugs etc, which contribute to the management of *Helicoverpa.*
- *Helicoverpa* incidence can be noticed in August in some fields, but the infestation is very low and sporadic and does not warrant intervention.

SEPTEMBER

Early reproductive phase

- *Helicoverpa* incidence starts in this period. Scouting must be done in at least 50 plants per hectare. Thresholds of 25 larvae/50 plants should be considered for spray of Endosulfan. If egg populations @ more than one egg per plant is also noticed simultaneously, it would be advisable to take up one application of pyrethroid before mid-October only. Pyrethroids have strong contact action on moths; are effective on younger larvae and are ineffective after mid-October due to increase in resistance levels and also due to presence of all stages of larvae. It is advisable to add 1 litre/ha of Sesamum oil to pyrethroids as it helps in counteracting resistance. Sesamum oil shoud never be mixed with any other group of insecticides.
- Application of biorationals (HaNPV @ 250 LE at 6 x 10^9 PIBs /LE, Trichogramma egg cards @150,000 eggs /ha, Neem seed Kernel Extracts 5% spray) can be taken up on egg based thresholds at 50 eggs/50 plants. It must be remembered that biorationals work on either eggs or young larvae only and hence the application would be beneficial if restricted to initial phases of pest infestation i.e up to mid-September. This also helps in conservation of natural enemies.
- Do not use any unregistered compounds such as botanical extracts, neem formulations etc. It is better to use neem oil or aqueous extracts of 25 Kg neem seed kernel /ha, instead of any commercial formulations.
- Use of endosulfan should be encouraged only as early season spray (resistance levels in *Helicoverpa* have been found to be invariably low early in the season), as it is relatively less toxic to natural enemies.
- Pyrethroids should be used only once. Synthetic pyrethroids either as over dose or repeated sprays lead to excessive whitefly flare up.
- Set up pheromone traps @ 5/ha for *H.armigera* to identify brood emergence.
- It has been found useful to spray 2% DAP by the end of September.

OCTOBER

Peak reproductive phase

- Do not spray pyrethroid and Endosulfan after second week of October as resistance levels in *Helicoverpa* increase after this period to these chemicals.
- American bollworm causes maximum damage during this period.
- Resistance levels against certain organophosphate group of insecticides (Quinalphos, Chlorpyriphos & Profenophos) and carbamates such as methomyl have been found to be relatively lower in most populations tested. Hence, it is preferable to use these as effective larvicides during mid-season (Sept-Oct) based on ETLs (20 larvae/20 plants) when the situation warrants.

- Pyrethroid resistance is high in many parts of India. These can be effective on *Helicoverpa* only on younger larval stages or adults or if used along with synergists such as sesamum oil However, pyrethroids are still effective against spotted and pink bollworm. Hence pyrethroids can be used either as early season sprays to target spotted and pink bollworm *or Helicoverpa* moths and young larvae.
- Handpicking of larvae 2-3 days after insecticide sprays effectively eliminates any surviving population which can cause future resistance problems.
- Always use insecticides as need based applications as per threshold levels. The keys to obtain better result from the use of insecticides are
  Right timing- right chemical- right dosage and right method.
- Always target younger stages of *Helicoverpa* as younger stages of resistant larvae are known to get killed at normal recommended doses.
- Rotation of chemical groups helps in preventing the build up of resistance against most insecticides, especially carbamates, organophosphates and endosulfan.
- Set up pheromone traps @ 5/ha for pink bollworm. Eight moths /trap/night for three consecutive nights is the action threshold.

NOVEMBER-DECEMBER

- *Helicoverpa* may persist till second week of November. Based on thresholds of 20 larvae / 20 plants carbamate insecticides such as Methomyl or Thiodicarb may be used during this period.
- Pink bollworm infestations are usually high during November, but are rarely noticed by farmers. It is advisable to use a single application of any pyrethroid at a threshold level of 8 moths/trap/night for three consecutive nights in pheromone traps. It must be remembered that pheromone septa need to be changed once a fortnight.

Specific recommendations for South India

1. Avoid cultivation of bushy cotton varieties.
2. Quality control on hybrid seed production and marketing must be enforced.
3. Pesticide dealers must be trained on plant protection aspects.
   Quality control of pesticides must be enforced.
4. Unregistered compounds such as botanical extracts, neem formulations etc. must be avoided
5. Egg batches of *Spodoptera* must be handpicked.
6. Light traps are very effective in *Spodoptera* management and must be used.
7. Pheromone traps can be very effectively used as monitoring tools.
8. Insecticides such as monocrotophos are not at all effective against either *Helicoverpa* or *Spodoptera* and must be avoided.
9. Insecticides such as pyrethroids are effective against moths and younger larvae of *Spodoptera* and *Helicoverpa* and may be used based on pheromone trap counts.

ANNEX 2: APPROPRIATE INSECTICIDES FOR USE IN IPM/IRM PROGRAMMES ON COTTON

Insecticides of category 1a, (extremely hazardous) eg. methomyl, monocrotophos, metasystox and phosphamidon have been deliberately avoided.

Insecticide	Activity	a.i /ha	Commercial names
Biorationals			
Neem seed kernel extract (NSKE)	Antifeedant	25 kg seed /ha	Azadirachtin based formulations : Bioneem, Econeem, Achook, Margocide, Multineem, Neemactin, Neemark, Neemazal, Neembicidin, Neem Gold, Neemnath
HaNPV	Stomach	3×10^{12} PIBs /ha	Commercial Formulation; Elcar PIBs = Polyinclusion bodies
Cyclodiene			
Endosulfan	Non-systemic, stomach and contact	Sucking pests 525-875 g a.i/ha, Bollworms 875-1050 g a.i/ha	Agcel, Dawn, Devisulfan, Endocel, Endocin, Endomal, Endosaan, Endoset, Endostar, Endotaf, Endoveer, Endovip, Hexasulfan, Parasulfan, Parrysulfan, Ricksulfan, Alfasulfan, Speed, Spicsulfan, Thiodan
Carbamates			
Thiodicarb	Systemic, contact	Bollworms 1500 g a.i/ha	Thiodicarb, Larvin
Carbaryl	Slight systemic, contact and stomach	All cotton pests 1000 g a.i/ha	Sevidol, Sevin, Sevinflo, Taffin
Insect growth regulator			
Diflubenzuron	Non-systemic	Lepidopterans 75 –100g a.i/ha	Dimilin
Organophosphates			
Acephate	Broad spectrum systemic, ovicidal, contact and stomach	Jassids, Whitefly 292 g a.i/ha; Bollworms 584 g a.i/ha	Acatin, Ace, Aceveer, Acevol, Afasan, Asataf, Daraphate, Gaycep, Growtaf, Moltthene, Orthene, Starthene, Tremor, Tameron Gold
Chlorpyriphos	Non-systemic, contact, stomach & vapour action	All cotton pests 250 g a.i/ha	Blaze, Chlorosan, Chlorvip, Classic-20, Dursban, Fantom, Gayachlor, Gold 25EC, Growban, K-Ban, Lethal, MIG-20 TC, Pyrivol, Radar, Strike, Suban, Tricel, Trishul
Dicofol	Non-systemic, contact acaricide	Mites 500-1000 g a.i/ha	Colonel, Dicomol, Diumite, Flush, Hexakel, Hondakel, Hycofol, Kelthane
Dimethoate	Systemic, stomach and contact	Aphids, Jassids Thrips, 100-200 g a.i/ha	Daragor, Demacin, Dimesaan, Dimoken, Diveer, Hexagor, Methovip, Parry Dimate, Rogor, Romal, Tara, Ultragor
Profenophos	Non-systemic, stomach and contact	Bollworms 750 –1000 g a.i/ha	Curacron, Kitazin
Triazophos	Translaminar stomach and contact	Cotton pests 600-800 g a.i/ha	Hostathion, Sutathion
Quinalphos	Translaminar, stomach and contact	Bollworms 500 g a.i/ha	Bayrucil, Ekalux, Flash, Katerphos, Krush, Nag, Quinalmol, Quinaltaf, Quinalveer, Quinalvip, Quinasaan, Quinocin, Spicquinal, Starlux, Suquin, Grolux

Synthetic pyrethroids			
Alpha – cypermethrin	Non-systemic, stomach and contact	Bollworms 15-20 g a.i/ha	Alphaguard, Alphakil, D-alpha, Growmax, Nagarjuna-Alphamethrin, Pestothren, Stop, Samco-alphamethrin
Fenvalerate	Non-systemic, stomach and contact	Bollworms 75-100 g a.i/ha	Darafen, Fencin, Fencron, Fenfen, Fenkil, Fenmol, Fenok, Fensaan, Fenvip, Field Marshall, Frofen, Milfen, Parryfen, Spicfen, Starfen, Sumicidin
Cypermethrin	Non-systemic, stomach and contact	Bollworms 40-70 g a.i/ha	Ankush, Arjun, Basathrin, Bilcyp, Crop Master, Cybil, Cypercin, Colt, Cyperkil, Cypersaan, Cypervip, Cyperveer, Cypermil, Cyprux, Gaythrin, Growcyp, Helothrin, Indothrin, Polytrin, Ralothrin, Silver, Spicthrin, Starcyp, Ultramethrin, Ustaad, Volcyper
Deltamethrin	Non-systemic, stomach and contact	Bollworms 12.5 g a.i/ha	Decakill, Decis
Permethrin	Non-systemic, stomach and contact	Bollworms 100-125 g a.i/ha	Ambush, Corsair, Dragon
Lambda – cyhalothrin	Non-systemic, stomach and contact	Bollworms 15 –25 g a.i/ha	Karate

Dosage recommendations : Directorate of plant protection and quarantine, Faridabad.