Management of Insecticide Resistant *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Cotton in India

D.A. Russell[1], *J. Singh*[2], *D.R. Jadhav*[3], *T. Surulivelu*[4], *A. Regupathy*[5] *and K.R. Kranthi*[4]

[1]Natural Resources Institute, Kent, ME4 4TB, UK
[2]Punjab Agricultural University, Ludhiana, India
[3]ICRISAT, Hyderabad, India
[4]Central Institute for Cotton Research, Nagpur and Coimbatore, India
[5]Tamil Nadu Agricultural University, Madurai, India

ABSTRACT

Helicoverpa armigera (Hübner) was responsible for some $500 million of damage in India in the 1997-8. Insecticide resistance levels have been monitored routinely at sites throughout the country since 1992 using discriminating dose assays. Resistance to pyrethroids is ubiquitous and stable at around 50-80% in most areas. Organophosphate and endosulfan resistance is stable at around 20-50%. Carbamate resistance is low. There is currently no significant resistance to Bt. Putting in place effective, economic, insecticide-based programmes that do not exacerbate the resistance problems, is a priority. Field trials from 1992-5 at ICRISAT developed appropriate IPM/IRM practices in pigeonpea and cotton. In 1995-6 these were taken into 'split-plot' IPM/IRM farmer trials in Andhra Pradesh (AP). Seed cotton yields were slightly enhanced with a 23% reduction in the number of insecticide sprays and a 57% reduction in the a.i. applied. In expanded trials in 1996-7 trials in AP and Tamil Nadu, insecticide use was reduced by over 40% and yields enhanced by 30%. Components of the package included appropriate varietal selection, seed quality and agronomy and improved spraying practices with quality materials based on scouting to simple economic thresholds. Early season spraying for sucking pests was avoided by the use of systemic seed dressings. The sequence used for bollworms was: Eggs: at low numbers - neem; at high numbers - profenofos, Larvae: 1st round: endosulfan; 2nd round OPs (quinalphos or chlorpyrifos); 3rd round, carbamates (carbaryl); 4th round - pyrethroids (cypermethrin, fenvalerate, deltamethrin or lambda cyhalothrin). In the 1997-8 season farmer participatory demonstrations were undertaken in four states (Punjab, Andhra Pradesh, Maharashtra and Tamil Nadu). In all areas spray applications were at least halved with respect to non-participating farmers' and yields rose by at least a third. The work was expanded in the 1998-9 season.

Introduction

The nation-wide monitoring of insecticide resistance in *Helicoverpa armigera* by the collaborating laboratories of the Indian Council for Agricultural Research (ICAR) *National Helicoverpa Network* is reported in Regupathy *et al.* (this volume) and our current understanding of the mechanisms underlying the resistance by Kranthi (also this volume). Details can be found in the issues of the *'Podborer Newsletter'* produced by the network and in numerous arising publications (e.g. Armes *et al.*, 1992; Armes *et al.*, 1994; Jadhav *et al.*, 1996). Armes *et al.* (1996) based conclusions on these data and on the results of a wider survey of 98 field sites across India, Nepal and a single site in the Pakistan Punjab.

Pyrethroid resistance is ubiquitous and stable at around 50-80% in most areas. Synergist studies show both mono-oxygenase and esterase mediated metabolic mechanisms to be important. Nerve insensitivity has been demonstrated from Andhra Pradesh and Maharashtra and declines in cuticular permeability have been demonstrated in a New Delhi strain. Organophosphate and cyclodiene (endosulfan) resistance is stable at around 20-50%, probably mainly mediated by enhanced levels of mixed function oxidases. Resistance to carbamates is present in the Punjab and AP but is currently at low to moderate levels. Baseline diet incorporation studies showed no significant resistance nationally to *Bacillus thuringiensis*. It is probable that much of the *H. armigera* resistance to pyrethroid, organophosphate and carbamate insecticides in the Indian sub continent can be attributed to an inherited or inducible mixed function oxidase complex (Armes *et al.*, 1996). However, it is becoming clear that esterase mediated mechanisms, reduced cuticular penetration and nerve insensitivity also have a part to play. Metabolic

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resistance to pyrethroids seems to impose a relatively low fitness cost, with resistance being maintained unaltered for several generations at least in laboratory populations (K.R. Kranthi unpublished data). The fitness cost of nerve insensitivity seems likely to be higher (McCaffery *et al.*, 1997) and may be implicated in the rapid end of season declines in pyrethroid and OP resistance seen in heavily sprayed areas.

Figure 1 shows summary data on national resistance levels for the main categories of insecticide in current use in India. The international discriminating dose for cypermethrin is 0.1µg/µl but in most of India, larvae are highly resistant and this dose doesn't discriminate anything. Consequently, a dose of 1.0µg was used throughout the country (10 times the usual dose), except in S. India where *H. armigera* is less resistant to pyrethroids. The Indian resistance position in a global context is reviewed in McCaffery (1999). The position in Pakistan is presented by Ahmad *et al.* (1998). New laboratories for whitefly (*Bemisia tabaci* (Gemm.) resistance studies at ICRISAT and the Punjab Agricultural University have shown significant resistance to cypermethrin, acephate and monocrotophos but continued susceptibility to chlorpyrifos, profenofos, triazophos and the recently registered nicotinyl, imidacloprid (D. Singh and D.R. Jadhav unpublished).

Armes *et al.* (1994) surveyed the position re IRM prospects at the First World Cotton Research Conference. The current paper updates the field implementation progress since then.

Development of practical resistance management strategies

Experience in other countries

By 1989 there were national resistance management strategies in place in Egypt and Zimbabwe (in an attempt to prevent the development of synthetic pyrethroid (SP) resistance in lepidopterous pests of cotton) and in Australia, where combating the existing SP resistance in *H. armigera* was the goal (Sawicki *et al.*, 1989). In Australia the two main factors influencing the frequency of pyrethroid resistance were shown to be dilution of the resistant population by insects entering it from refugia and the pyrethroid selection pressure itself (Forrester *et al.*, 1993). The Australian strategy recommends the avoidance of broad-spectrum insecticides early in the season, the alternation of chemical groups, provides spray thresholds and advises against the re-spraying of apparent control failures with chemicals in the same group. Insecticide groups are alternated through time to minimize resistance pressure. As refugia became contaminated, the effectiveness of this strategy declined and pyrethroid resistance levels slowly increased in all areas. It seems that the IRM strategy favoured the oxidative metabolic resistance pathway over the nerve insensitivity resistance mechanism (Forrester *et al.*, 1993). The use of piperonyl butoxide as a synergist (Forrester *et al.*, 1993) did not extend the field life of the pyrethroids against *H. armigera* for long. In practice, Australian growers are coming to rely heavily on the *Bt* transgenics and chemistries with novel modes of action for control of *H. armigera.*

Resistance breaking pyrethroids

Biochemical studies have suggested the development of resistance breaking pyrethroids where oxidative metabolic pathways are the resistance mechanism (Forrester *et al.*, 1993) and considerable commercial effort has been put into their development. Ahmad *et al.* (1997) show variations in the resistance to pyrethroids in Pakistan that depend on their chemical structure. Resistance was highest to cypermethrin and cyfluthrin, intermediate to alpha-cypermethrin and deltamethrin and lowest to zeta-cypermethrin, bifenthrin and lambda-cyhalothrin. Whether these differences represent differences in the ease of development of resistance to the various structures or merely reflect the differences in their use and the consequent selection pressure is not yet clear.

Bt transgenics

The use of *Bt* transgenics provides a potential mechanism of escape from the problems of conventional insecticide resistance. *Bt* spraying is not yet widespread in India, in part due to the relatively high cost of formulations. This situation may change if resistance continues to increase to the currently recommended conventional insecticides. Discussions are well advanced between the multinational patent holders and seed companies in India and *Bt* hybrid transgenic material is being actively developed. *Bt* transgenics could be released on to the market as early as 2000. A baseline study of *Bt* resistance was carried out using a diet incorporation assay with larvae from Bangalore, Hyderabad, Delhi, Coimbatore, Guntur, Varanasi and Nagpur. LD_{50}s 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.R. Kranthi unpublished data). Resistance factors of 35-40 fold have, however, been generated through laboratory selection over six generations (K.R. Kranthi pers. comm.) and cross-resistance to various Cry toxins demonstrated. No nationally agreed resistance management strategy is in place against the eventual release of transgenics in India.

Refugia strategy

The maintenance of an effective source of susceptible individuals in the cropping system while applying sufficiently high doses of toxic materials to kill the homozygous recessive resistant and heterozygous phenotypically resistant individuals, maintaining resistance only in rare, functionally recessive heterozygotes, has been the cornerstone of the Australian strategy (Forrester, 1994). For *H. armigera*, this strategy requires that refugia should be spatially and temporally adjacent to the sprayed, or *Bt.* transgenic, fields. Australian growers are advised to maintain at least 20% if their cotton as non-transgenic material in order to provide a refugia for susceptible insects. Recent work in Australia suggests a probable crash in single gene *Bt* transgenic refugia efficiency after about four years (12 generations) if all heterozygotes are not killed and the need for at least a 50% refugia to get the best long term use of *Bt* transgenics for *H. armigera* control (Roush, 1999). It is very difficult to see how a voluntary code for the maintenance of refugia could operate effectively in India, especially if varietal transgenics capable of breeding true become available from the national programme laboratories. It may be argued that the small sizes of individual fields and the availability of alternate host plants provides an effective refugia without the need for special arrangements. This needs further study but it should be noted that this situation has pertained for conventional insecticides including pyrethroids but has not prevented the development of significant pyrethroid resistance nation-wide in all host plants sampled (Armes *et al.*, 1996). It seems likely that in India refugia of 100% pyrethroid susceptible *H. armigera* no longer exist.

Alteration of chemical groupings

IRM strategies in India, as elsewhere, have included strong recommendations for the alternation of chemical groups in successive spray rounds. Although this makes good resistance management sense when all the crop in a local area is synchronized in its planting date and phenological development (as is true for example in the very large farms in Australia, or the tightly state regulated growing system in Egypt), the diversity of agronomic practices, of varieties and even species of cotton planted (especially in north India) mean that a farmer following the recommendations may find himself spraying chemicals of groups different to that being sprayed by another farmer in the next field at the same time who is also following the recommendations. Worse, succeeding generations of *H. armigera* larvae may be sprayed with materials from the same resistance groups by farmers in adjacent fields and certainly in adjacent districts. This is not something that resistance managers can afford to ignore. Even if the major pesticide companies agreed to a voluntary restriction on the sale of certain chemical groups at certain times of the season (as is now in place in Pakistan), the widespread presence of small local formulators and the presence of a very extensive dealer network, make it unlikely that such a move would have any impact in practice. The complex patterns of cross resistance between chemical groups and within groups such as the pyrethroids and OPs further complicate the use of this strategy, even under ideal management conditions. The evidence reviewed by Tabashnik in 1989 suggests that the use of pesticide mixtures, now common in India, has not delayed resistance development.

New chemistries

In the situation outlined above it is hard to escape the conclusion that insecticide based control of *H. armigera* and associated insects in India desperately needs new chemistries with different resistance profiles. New chemistries showing promise for the control of heliothine lepidoptera in other parts of the world include the new chitin synthesis inhibitory benzoyl phenylurea, novaluron; the ecdysone agonist, tebufenozide; the avermectin, emamectin; and certain pyrroles, phenyl pyrazoles and nicotinyls. (Ishaaya and Degheele 1998; McCaffery, 1999). Chlorfenapryl, which acts on mitochondrial ATP metabolism, is activated by enhanced levels of mfos and may may be particularly useful in managing mfo mediated resistance.

Effective whitefly control in strict IPM systems has been achieved in both Israel and Arizona with single applications of the chitin synthesis inhibitor, buprofezin and juvenile hormone mimic, piriproxyfen. The benzyl phenylurea, novaluron shows great promise as a contact insecticide. The nicotinyls imidacloprid, acetamaprid, nilepyram and thiamethoxam have proved useful as have the feeding suppressant, pymetrozine; the thiourea derivative, diafenthiuron and the avermectin, abamectin (Ishaaya and Degheele, 1998; Denholm *et al.*, 1999).

Other factors contributing to poor control

While this paper concentrates on the resistance-based causes of insect control failures, there are a number of other factors that are at least equally important and whose impact is often blamed incorrectly on insecticide resistance. Although definite figures are hard to obtain due to the litigatious nature of the problem, a very high proportion (perhaps as high as 25% in N.India) of cotton pesticides sold through the dealer network, are for one reason or another sub-standard in the quality or quantity of the active ingredient or in the material used in the formulation.

Poor application quality is also a very significant cause of control failures. In addition to the questions of inappropriate nozzles and sprayers, the architecture of the crop is often a major impediment to achieving the application of a lethal dose of insecticide. Preliminary trials in the Indian Punjab have shown that none of the standard spray methods deliver insecticide to the under-surface of leaves, nor efficiently to the lower third of the plant, especially where high density, over-fertilized stands make spray penetration almost impossible with conventional equipment (J. Cooper and J.Singh pers.comm.).

In designing IRM strategies that benefit both the individual grower (through improved control at lower cost) and the wider community (through retaining the efficacy of important crop protection chemicals), addressing these concerns with, for example, shorter season cotton varieties showing some insect (especially sucking pest) tolerance and with more appropriate architecture for spraying, will take us a long way towards meeting our goals.

IPM/IRM 'Best bet' strategies in India

It is clearly a long-term goal of IPM strategies to work towards a crop management system that minimizes or removes broad-spectrum toxic materials. The continued use of materials, many of which are now banned elsewhere in the world on environmental and health grounds, is not something that should be supported. Even endosulfan, used at the rates recommended in India, has a WHO class II (moderately hazardous) rating. However, the Indian cotton system has been severely altered in recent decades by the intensive use of pesticides. Even where pesticides are not sprayed at all, as on a 250 acre block in the Indian Punjab in 1997, numbers of beneficials can 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. Armes *et al.* (1996) suggested that with the complex cross-resistance pattern pertaining, a first aim should be an overall reduction in selection pressure that should reduce or remove at least the nerve insensitivity component of resistance in heavily sprayed areas, allowing a return to 'manageable' pyrethroid resistance levels of 40-60% in most areas.

Current status of other IPM technologies

National trials have been underway for some years to test the efficacy of various treatment packages ranging from 'fully non-chemical' to 'fully chemical'. The importance of neem based products, NPV, *Bt*, the use of *Trichogramma* spp. as egg parasitoids and marigold and other plants as trap crops for *H. armigera* eggs has been explored. Considerable success is being achieved on an experimental basis and a great diversity of results and recommendations have arisen from these trials. 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. Rameis and Shanower (1996) survey the efficacy of bio-control agents for *H. armigera* control. Recent trials of artificial pheromone for mating disruption of *H. armigera* in the Indian Punjab (J. Singh, unpublished data) and in Pakistan (Chamberlain *et al.* in prep.) have shown that mating suppression in cotton blocks is achievable but that economic control following immigration of large numbers of mated females in September is not. It is our understanding from this literature and the overall analysis to date of the national trials in the Indian Council for Agricultural Research programme for the development of IPM packages under selective crop conditions, that conventional, insecticide-based cotton pest control, judiciously applied, is still the most reliable and cost-effective way of maintaining yields in most areas and years. The availability of biorational products of proven efficacy is not such that it is seen as currently responsible to recommend them for wider farmer use.

Current Indian IPM/IRM rationale

There are very poor prospects for adoption of pest management recommendations in India that rely for their efficacy on widespread simultaneous adoption by large numbers of farmers forgoing some current benefit for future advantage. Consequently, the development of IRM recommendations has followed the path of identifying readily available and familiar components, each of which provide a benefit when used alone, but which, if used together, should minimize the development of future resistance problems while giving effective, robust, control of the pest complex at an economically affordable level. As such, they represent a package of 'best-bet' practices for cotton management that address the IPM and IRM components simultaneously.

Development of an IPM/IRM package for H. armigera

Field trials from 1992 to 1995 within an NRI/ICRISAT collaborative project aimed at establishing useful components for IRM on cotton and pigeon pea. The results are summarized in Armes (1966). The conclusions of relevance are:

- Avoidance of early season sprays against jassids is important for the subsequent successful reduction in spray applications.
- Varieties planted at high densities are very difficult to protect from pest damage.
- Few of the insecticides applied at recommended rates effectively controlled *H. armigera*. They

were increasingly ineffective on larvae over 3-4 days old and many neonates were hidden from the spray, being concealed within bracts.

- Hand picking of larvae (even weekly) had only a marginal impact on yields (< 5%).

1995-7 'Best-bet' IPM/IRM trials

Consideration of the results from the network trials gave rise to a farmer field split-plot trail in the Rangareddi District of Andhra Pradesh in 1995. The components of the IPM/IRM package were:

- *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 fertilizers; removal of terminal shoots at 90 days.
- *Insecticide application* -avoidance of early season spray applications (use of systemic insecticide); twice weekly pest scouting; 1-2 pyrethroids only, late in the season; alternation of chemical groups in successive spray rounds; no re-treating spray failures with the same chemical.
- *Resistance monitoring* - use of monitoring data for decisions on which chemical groups to apply on the basis of resistance gene frequencies at that time of the season.

Results showed the seed cotton yield in the IRM areas to be slightly higher at 1,561kg/ha (range 1,022 – 2,448) compared to 1,488Kg (992-2,3312) in farmer managed areas. The number of applications was reduced by 23% from 17 (range14-20) to 13 (10-15) and a.i./ha by 57%, from 13,967gm to 6,008gm.

The split plot trials were expanded to include a site near Coimbatore in Tamil Nadu in 1996. In both areas, insecticide use was reduced by c.40% over the farmer managed areas and yields increased by c.30%.

1997-8 'Best-bet' IPM/IRM trials

Demonstrations were expanded to four sites (Punjab (Punjab Agricultural University led), Maharashtra (Central Institute of Cotton Research, (CICR) Nagpur led), Tamil Nadu (CICR Coimbatore and Tamil Nadu Agricultural University led) and Andhra Pradesh (ICRISAT led). The split-plot design was abandoned and farms from adjoining areas and villages were used as 'controls'. Community involvement and farmer enthusiasm and understanding was engendered through the close involvement of the project socio-economists from ICRISAT and NRI in the design and implementation of the trials. Project staff were based in the area to ensure continuity of advice to the farmer, who made the pest control decisions based on his own scouting, supplemented by advice from project staff, especially in the first year of the programme.

The components of the IPM/IRM package for southern India are summarized below and the need-based schedule of chemical use detailed in Table 1. The package took existing University and state recommendations into account for IPM and local knowledge of the efficacy of particular materials within an IRM context. Modifications of detail were necessary for the predominantly irrigated Punjab where the pest sequence is different, and earlier use of pyrethroids was made in Maharashtra, to take advantage of the relatively high susceptibility of larvae early in the season.

- *Seed:* Use certified varieties or hybrids that are tolerant to sucking pests.
- *Spacing*: Wide spacing (specified)
- *Growth control*: Remove terminal shoots at 90 days (rarely done)
- *Assisting beneficial organisms*: Plant cowpea on the bunds (some uptake); delay spraying toxic materials as long as possible; use seed treatment to remove the need for early sucking pest sprays.
- *Fertilizer*: Need based after soil analysis (details provided); avoid excessive nitrogen.
- *Spray decisions*: Do not use calendar method; follow economic thresholds; follow the recommended pest/ appropriate pesticide list provided; rotate chemical groups; do not re-treat 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
- *Scouting:* weekly scouting 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: Use seed treatment (effective to 40-60 days from planting). Spray action thresholds provided for jassids, thrips and 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.

Results of the 1997-8 demonstrations

Results are presented in Table 2. In the Andhra Pradesh trial, spraying, even the non-participating farmer applications in the same village, were down from over 20 in 1996-7 to 13-14 in 1997-8, in part due to a level of spread of the 'best-bet' philosophy within the local area. The trials in the Punjab were very adversely affected by the high *H. armigera*, thrip and whitefly numbers that prevailed right across the region and by extremely wet weather throughout the season. Nevertheless the IRM participating farmers have achieved acceptable yields with an average of seven insecticides while the surrounding area averaged 15-20 applications for a significantly poorer result. Applications by participating farmers in Tamil Nadu were 75% lower than last year and c.63% lower than for non-participating growers.

Human health benefits are also considerable. As a rough marker of human health impact, the reduction in the average number of human dermal LD_{50} doses applied in participating and non-participating farmers fields was calculated, taking the number applications of each chemical, the quantity of active ingredient applied and the toxicity of the chemical into account (Figure 2) (Iyengar and Russell, unpublished data). Reductions varied from 47% in the Punjab to 92% in Maharashtra. Over 96% of the total dermal toxin impact in non-participating farmers' fields was from organophosphates.

Yield increases from the total package have been consistent across the three years of this work, demonstrating a sufficiently high increase in net profits to move cotton growing from a marginal activity to a profitable one for many farmers.

Detailed examination of farmer practices in the AP trial in 1997-8 showed that 66% of all applications were made with recommended materials when pests were over threshold, 19% were not necessary and 15% [illegible] target pest). All the unnecessary sprays were applied prophylacticaly in the early season against sucking pests. This reflected farmer unfamiliarity with the seed treatment imidacloprid. Of the inappropriate sprays, 76% were applied in response to above threshold *Helicoverpa* egg numbers (there were no recommended ovicidal chemicals available locally at the time). Both yields and profits were maximized at lower numbers of insecticide applications. Examination of the efficacy of materials in lowering pest numbers following application confirmed the economic thresholds as also being levels below which it was not possible to show any convincing pest reduction. Applied above threshold, metasystox performed convincingly against aphids and jassids, endosulfan against jassids, aphids and to an extent against *Helicoverpa* larvae, quinalphos against aphids, chlorpyrifos against whitefly and jassids and cypermethrin against whitefly, jassids and *Helicoverpa* eggs and larvae, confirming the position of pyrethroids in *Helicoverpa* control. It is this team's view that, except in years of exceptionally high pest pressure or unseasonable weather (as occurred in the Punjab in 1997-8), a further reduction in insecticide use of 20-40% is possible without compromising yields.

The above recommendations were adopted, almost in their entirety, at the final meeting of the Indian Council of Agricultural Research's *Helicoverpa Network* in May 1998 as the national recommendations for IRM for this species.

IRM/IPM Prospects

Given the highly mobile nature of *Helicoverpa armigera*, the areas under these recommended practices have been too low to date to demonstrate any effect on resistance levels, even locally. However. not only is the strategy proving highly economically beneficial for the individual farmer while meeting criteria for minimizing resistance development, but environmental and health hazards are also being reduced. If this level of compliance can be maintained and expanded over significant areas there is some hope of undermining at least the nerve insensitivity component of the existing resistance. Farmer enthusiasm is high and the village-focused. participatory nature of the work is resulting in a great deal of positive demand for the programmes from surrounding farmers and villages. The Government of Punjab took up the principles of the programme in 11 villages in the 1988-9 season. A further 9 villages are being supported from CICR Nagpur and three each by ICRISAT and CICR/TNAU staff from Coimbatore and Madurai with NRI/DFID support. ICAR institutions in these four cotton states are also adopting villages to demonstrate the methodology under national funding. It is hoped that with the co-operation of the extension services, pesticide dealers. the Insecticide Resistance Action Committee (IRAC), the Universities and ICAR institutes, the demand can be met in the years to come.

Further work needs to be undertaken urgently on the extent and significance of cross-resistance; the relationship between laboratory measured 'resistance factors' and field control levels achieved; and the principles behind the effective deployment of insecticide mixtures explored.

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Table 1. ***Control Schedule*** **(simplified) for the 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	Imidacloprid	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
		Dicofol 18 EC	

Table 2. Comparison of results from farmers participating in the 1997-8 'Best-bet' trials and those of non-participating 'control' farmers. (Maharashtra demonstration was 'split-plot' with 11 farmers. The other sites were fully participatory with 20 farmers/site).

Site	Mean No. of Spray rounds		Advantage for participators	
	Participants	Non-participants	Yield /ha	Net. profit /ha
Maharashtra	2.5	5.5	38%	$93
Andhra Pradesh	7.5	13.4	39%	$60
Tamil Nadu	3.2	8.7	34%	$180
Punjab	7.0	15.7	100%	$228*

*Non-participating farmers made a significant loss in this year of exceptionally high pest pressure.

Figure 2. Average % reduction in the number of human LD_{50} doses of all insecticide applied in the fields of farmers participating in the final year of trials compared to those not participating. (LD_{50} doses calculated for a 70Kg man for each chemical from WHO tables).

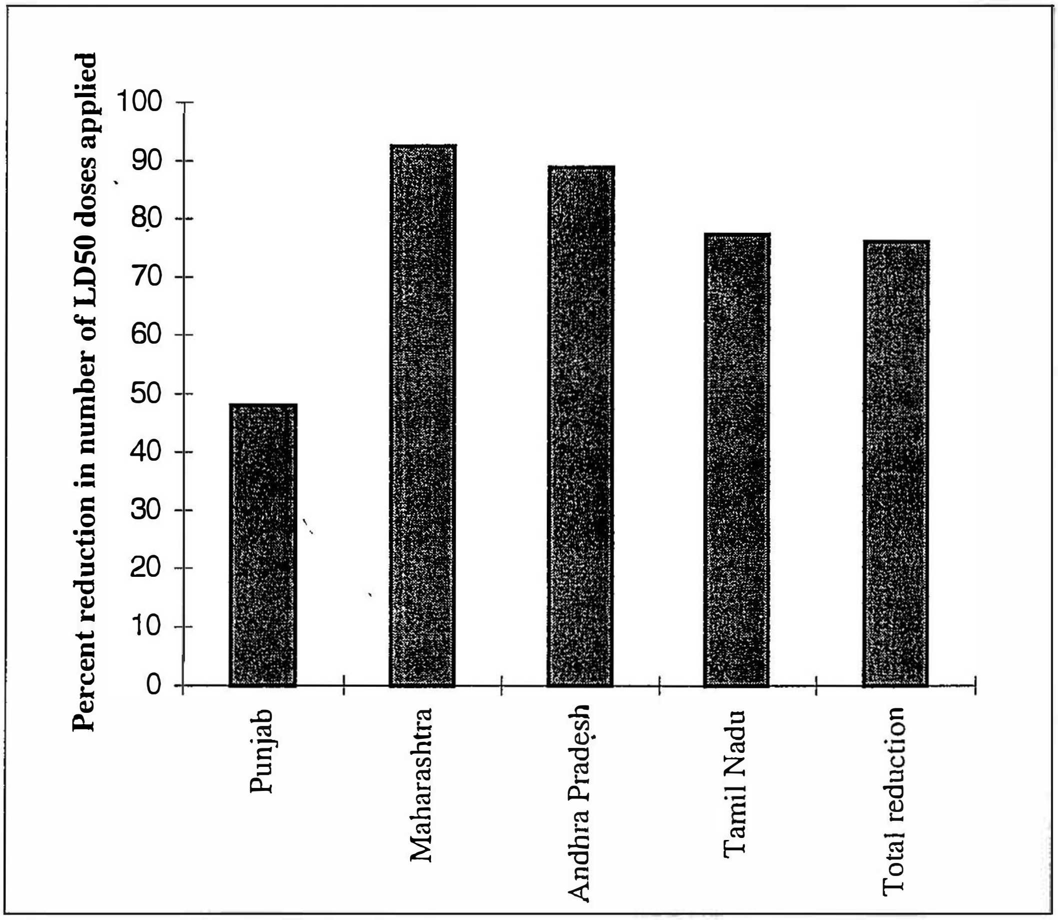

Figure 1. Seasonal averages of weekly measurements of percentage survival of *H.armigera* larvae to discriminating topical doses which would kill >95% of susceptible insects 1993-4 to 1997-8. From north to south: Punjab Agricultural University Ludhiana, Central Institute for Cotton Research, Nagpur, Maharashtra, ICRISAT, Hyderabad, Andhra Pradesh and Tamil Nadu Agricultural University, Coimbatoré, Tamil Nadu.