Developing and implementing insecticide resistance management practices in cotton ICM programmes in India

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ABSTRACT

Pyrethroid, organophosphate, carbamate and cyclodiene resistance levels for the cotton bollworm (*Helicoverpa armigera*) have been monitored routinely at sites throughout India since 1993 using discriminating dose assays. Resistance by *H. armigera* and other pests to commonly used insecticides is a severe constraint to cotton production in India. An integrated crop management strategy was developed aimed at maximising profit while minimising insecticide use and the impact of insecticide resistance. Appropriate varieties and agronomy, plus seed treatment where necessary, allow the first foliar insecticides to be delayed until at least 70 days from planting. Insecticides for fruit and leaf feeders are then rotated, taking account of seasonal shifts in their efficacy and the pest spectrum faced; with endosulfan first, followed by particular organophosphates, leaving one to two pyrethroid sprays until the late season when pink bollworm is also present. This system (customised for the different regions of India) was demonstrated in village participatory trials, reaching 24 villages across four states in 1998-9. In all areas the quantity of insecticide a.i. used was reduced by >29%; yields increased substantially and net profit rose $40 to $226/ha when compared with farmers not in the schemes.

INTRODUCTION

Insecticide use on cotton in India consumes 50% of the total agricultural insecticide on 5% of the agricultural land and is increasing at c.7% per year. Insecticides account for c. 44% of cotton growing costs nationally and c.19% of total production costs (ICAC 1998).

The American bollworm (*Helicoverpa armigera* Hübner) is recorded from over 20 crops and 180 wild hosts in India. Heavy spraying, particularly on cotton, resulted in resistance to cypermethrin in *H.armigera* (Dhingra *et al.* 1988). More limited recent survey work is also identifying difficulties with resistance in the whitefly *Bemisia tabaci*, pink bollworm (*Pectinophora gossypiella*), the leafworm (*Spodoptera litura*) and the spotted bollworm (*Earias vitella)*.

Resistance measurement and mechanisms

Detailed results from the long term monitoring operations for resistance in *H. armigera* (1993-1998) are analysed by Armes *et al.* (1996) and by Russell *et al.* (1998) who draw conclusions based on these data. The number of sites from which pyrethroid resistance was recorded rose dramatically from two in 1987 to 98 in 1993 (Armes *et al.* 1995 and 1996, Jadhav & Armes, 1996).

Pyrethroid (cypermethrin and fenvalerate) resistance is ubiquitous in *H. armigera* and is stable at 50-80% (close to 100% in coastal Andhra Pradesh). Synergist studies show both mono-oxygenase and esterase mediated metabolic mechanisms to be important. Nerve insensitivity has also been demonstrated from Andhra Pradesh and Maharashtra and declines in cuticular permeability have been demonstrated in a New Delhi strain. Organophosphate (quinalphos) and cyclodiene (endosulfan) resistance is stable at around 20-50%, and probably mainly mediated by enhanced levels of mixed function oxidases. Resistance to carbamates (methomyl) is present in the Punjab and Andhra Pradesh but is currently at low to moderate levels. A preliminary baseline study showed no resistance to diet incorporated *Bacillus thuringiensis* (LD_{50}s from 63-110 ng/larvae compared to the susceptible baseline of 54-60 ng/larvae). More restricted work with other lepidopterous pests of cotton has shown significant resistance to organophosphates in *S. litura* and to quinalphos and methomyl in *P. gossypiella*. *Earias vitella* is showing significant resistance to organophosphatesand carbamates in N. India. *Bemisia tabaci* resistance studies since 1997 in the Punjab and Andhra Pradesh show significant resistance to cypermethrin, acephate and monocrotophos but continued susceptibility to chlorpyrifos, profenofos, triazophos, endosulfan, and the neonicotinyl, imidacloprid. Of the considerable range of 'new' chemistries, effective in other parts of the world for bollworm and whitefly control, only imidocloprid and spinosad have been registered for use on cotton in India (in 1999 and 2000).

Table 1 summarises the currently available information for cotton pests. There is, however, a great deal of variation between areas, between seasons and within seasons at individual sites.

Resistance stability

In the only species so far tested, *H.armigera*, resistance to endosulfan and quinalphos declines rapidly in both the laboratory and the field in the absence of selective pressure. Pyrethroid resistance appears to be much more stable. The mechanisms underlying these relationships are discussed in Armes *et al.* (1996), McCaffery (1999) and by Kranthi *et al.* (1997 and in press).

Table 1. 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	Very high	Very 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 impair usefulness

Development of practical management of resistant insects

IRM strategies in India, as elsewhere, have included strong recommendations for the alternation of chemicals groups in successive spray rounds. The IPM strategy for southern India being recommended by the current research grouping, involves the use of profenofos when eggs only are present early in the season followed by the cyclodiene, endosulfan, an organophosphate (quinalphos or chlorpyrifos), a carbamate (carbaryl or thiodicarb) and finally pyrethroids (cypermethrin, fenvalerate, deltamethrin or lambda cyhalothrin). The complex patterns of cross-resistance between chemical groups and within groups such as the pyrethroids and organophosphates complicate the use of this strategy, even under ideal management conditions.

Potential components of IPM strategies

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* spp. 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, 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. Many organisations are exploring the use of trap crops, inter-cropping, oviposition deterrents and NPV. However, the availability of reliable products of proven efficacy is not such as to make it currently advisable to recommend them for wider farmer use and over 95% of farmers still rely on sprayed insecticides.

ICM/IPM/IRM DEMONSTRATIONS

Picking up on the results of work at ICRISAT in 1992-5 (Armes 1996), an expanding series of demonstrations of IPM within an integrated crop management context, which focused on minimising the impact of insecticide resistance, was undertaken in farmers fields in the 1996-7 to 1998-9 seasons. The scale of operations increased from 20 farmers in one state in 1995 to 1,650 farmers in 24 villages in 4 states in 1998. The details of the recommendations varied to take account of the agronomic appropriateness of particular varieties, the availability of irrigation, the local pest complex etc. Each component was intended to provide a stand-alone benefit even if not used in conjunction with all components of the package:

The trials were undertaken by the village community in which the farms were based. 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. Practical advice and decision making support was provided to the farmers on two models. Young village residents were trained as IPM support staff (three per village) and employed throughout the cotton season in the Punjab, Andhra Pradesh and Tamil Nadu. Each group of villages was supported with one IPM qualified field research assistant from the parent research organisation. This model was moderately successful. In Maharashtra support was provided during the cotton season by final year BSc Agriculture undergraduates from Akola University (two resident in each village) as part of their 'village placement' training for the degree. This model was extremely successful with both farmers and students and is recommended where the academic system allows it. The field liaison was supported evening village meetings and with cotton IPM booklets and brochures in local languages, sold to the farmers. These were extremely popular and have run through several editions.

The components of the IRM methodology for central and southern India are summarised below The advice provided took into account existing University and state recommendations 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):

Seed: use of certified varieties or hybrids that are tolerant to sucking pests;
Spacing: wide spacing (specified)
Assisting beneficial organisms: delay in spraying toxic material as long as possible; use of seed treatment to remove the need for early sucking pest sprays;
Fertiliser: Need based after soil analysis (details provided); avoid excessive nitrogen.
Spray decisions: following intervention thresholds below which application have been shown to be uneconomic; rotation of chemical groups; not re-treating 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; squeezing *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; spray at one live larva per plant or 10% of fruit showing damage;
Green and open boll period: all bolls on 50 plants examined for fresh bollworm damage. Spray at 5% *H. armigera* or 10% bollworm damage overall.

Table 2. Chemical 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	1st 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

RESULTS

Demonstrations were undertaken with 1,650 farmers in 1 village in Tamil Nadu, 3 in Andhra Pradesh, 9 in Maharashtra and 11 in the Punjab in 1998-9. A summary of the results is presented in table 3.

Helicoverpa armigera and *B. tabaci* numbers were devastatingly high across the Punjab in 1998 with numbers above the intervention thresholds for 107 days out of the 140-day 'season'. The number of applications was not reduced but the use of mixtures and of the more toxic materials declined dramatically.

Although they comprised less than 50% of the spray rounds in any given state, organophosphates were responsible for 96% of the human dermal toxicity hazard in the non-project villages. Pyrethroids, which have other problems in IPM programmes, accounted for less than 1% of the overall risk. The estimated total impact on beneficial arthropods (using the published LD_{50}s) was reduced by 85% for egg parasitoids, 62% for larval ectoparasitoids, 78% for ladybird predators and 63% for lacewing predators (Iyengar and Russell in press).

Table 3. Outcome for IRM crop management scheme: participating farmers compared with matched control farmers from nearby villages.

	Punjab	Tamil Nadu	Andhra Pradesh	Maharashtra
Reduction in pesticide use % (no. spra	-2	46	44	95
Reduction in pesticide use % (a.i./ha)	29	42	69	92
Reduction in plant protection cost %	21	39	55	88
Yield increase (%)	49	17	31	70
Net increase in profitability ($/ha)	40#	93	125	226#
Reduction in health hazard* (%)	48	77	89	92

* Calculated on the basis of human LD_{50} dose reductions from the WHO tables for the particular chemicals involved
# Non-participating farmers were operating at a loss.

Uptake of results

The Indian Council for Agricultural Research is supporting a suite of village demonstrations of the project outputs in the four states. The Common Fund for Commodities (of the UN) is providing support for a US$4 million project to extend and implement the results of this work in China, Pakistan, India and Africa from 2000 – 2004.The knowledge gained is being fed into the six country, EU-funded, Asian Cotton IPM Farmer Field School project (2000-2004).

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