CROP PROTECTION PROGRAMME
&
NATURAL RESOURCES SYSTEMS PROGRAMME

A systems approach to sustainable insect pest management in irrigated cotton in India

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1 Executive summary

Some 60 million people derive income from cotton in India, with cotton contributing approximately 30% of the country's export earnings. Average yields are highest in the irrigated Punjab (471 kg lint/ha) which produces 13% of India's production on 8% of the cotton area. Since the late 1980s production in the Punjab has stagnated or declined, because of reduced profitability caused by uncontrollable insecticide-resistant cotton pests. Caterpillars of the American bollworm or gram podborer, *Helicoverpa armigera,* and the sap sucking cotton whitefly *Bemisia tabaci*, are the most important insect pests of cotton in the northern cotton growing zone of India. *Bemisia tabaci* is also a vector for Cotton Leaf Curl Virus (CLCuV). The escalating cost of increasingly ineffective insecticide applications against these two species was rendering cotton production uneconomic - a disaster for farmers, many of whom farm land which is not suitable for other crops.

Studies of 260 farm households in 13 villages showed that while gross cotton yields and gross revenues per hectare had declined since 1994, over the same period, insecticide use increased by 22%, putting costs of pest management up by 50%. The project demonstrated that the increasing insecticide use was selecting strongly for evolved resistance to the main chemicals used to control bollworms (cypermethrin, fenvalerate, quinalphos and endosulfan) and whiteflies (cypermethrin, acephate and chlorpyrifos). This in turn encouraged application of more and stronger insecticides and mixtures to control the resistant pests - a classic 'pesticide treadmill'. Levels of insecticide resistance were monitored in the two key pest species and insecticide use recommendations developed.

The etiology of CLCuV was worked out; its crop and weed hosts identified; the relative efficacy of insecticides in limiting the spread of disease was examined and a range of CLCuV tolerant/resistant cotton cultivars identified.

Project recommendations were trialled on farms in two villages in 1997. 'Best-bet' pest management strategies, (including the use of appropriate varieties, plant spacing, fertilisation, pest scouting and improved spray application), were demonstrated in village-based, farmer-participatory trials. Despite a difficult season in terms of weather and insect pest pressure, the work was successful, reducing insecticide use by 40% and increasing yields by 10-20 %; stimulating great interest in the region. The message was promulgated at a number of fora including some very large farmer meetings in the cotton belt. A large scaling-up exercise was undertaken in 1998 in 11 villages, as an initiative of the Punjab Chief Minister and collaborating with state and national agencies involved in agricultural extension, input provision and cotton production. 1998 was the worst year on record for high pest levels in the Punjab. Nonetheless the use of undesirable pesticide mixtures and pyrethroids was reduced by half, the human health hazard reduced by 48% and the yields of participators were 49% higher than that of non-participators. Cotton production was profitable to participating farmers that year but not to farmers in the surrounding areas.

The project has produced a fuller understanding of the forces operating on farmers and formulated appropriate recommendations for insecticide use based on this knowledge. It has successfully addressed the goals of the two Programmes '*to minimise the impact of significant pests of cotton'* by reducing the cost and environmental impact of control, and to '*increase systems commodity production by optimising inputs and outputs*' by increasing yields by over 50% for participating farmers. Cotton pest management recommendations developed by the project have formed the basis of several further initiatives by the Government of India and others, including DFID, the Common Fund for Commodities (UN) and the EU, which will develop and transfer 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 and contributing approximately 30% of the country's export earnings in the form of cotton products and lint. 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 was primarily a result of increase in yield rather than total acreage, reflecting the development of high-yielding varieties and hybrids, improved agronomic practices and intensification of pest control measures. Of the nine cotton producing States in India, average yields are highest in Punjab (471 kg lint/ha) which produces 13% of India's production on 8% of the cotton area (total c.9,070,000 ha). Almost all the northern zone (Punjab, Haryiana and Rajisthan) cotton is irrigated (compared with 19% irrigated for central and southern India). However, since the late 1980s production has stagnated, or in some years actually declined. 1998-9 production was c.2.7 million tonnes of lint. Production has stagnated largely because of declines in profitability caused by uncontrollable insecticide resistant cotton pests. The American bollworm or gram podborer, *Helicoverpa armigera* and the cotton whitefly, *Bemisia tabaci* are the most important insect pests of cotton in the northern cotton growing zone of India and a large proportion of yield losses is attributable to attack by these species. For example, during the 1994/95 season in the State of Punjab, these key pests, *H. armigera* and the whitefly *Bemisia tabaci* (as a pest in its own right and as a vector of cotton leaf curl virus), caused a 30% reduction in cotton yield.

In the early 1990's farmers in the Punjab typically applied 5-9 insecticide sprays to cotton, but poor control in the 1993/94 and 1994/95 seasons necessitated frequent repeat applications and 10-15 sprays were not uncommon. This situation has continued to deteriorate with an average of approximately 12 sprays in 1997. Counting only the numbers of insecticides, masks the fact that the quantity of active ingredient per application is rising and that many of the applications (over two thirds in 1997) are now mixtures of insecticides, often at the full 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 (ICAC, 1998). Punjabi cotton farmers, having rather larger average farm sizes, higher inputs and historically larger yields to protect (441 Kg lint/ha in 1996-7 as opposed to a national average of 269Kg/ha (Malhan, 1998)), have increased pesticide use even faster than the national average and, in 1996-7, were spending an average of around 54% of their growing costs on plant protection (Malhan and Singh, 1999). This has pushed most cotton growers into 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 probable reasons for this increase in insecticide use. The land use pattern has intensified in the last 20 years with a greater number of potential hosts for both *H.armigera* and *B.tabaci* being grown in cycles which allow pest carry-over between crops. Insecticide quality is extremely variable. The requirements of the 1986 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. Formulation and labeling standards are poor and in many cases insecticides are deliberately miss-labeled, watered down or otherwise adulterated. This results in spray failures and the response of increasing applications of alternative materials. Owing to an arcane enforcement system, successful prosecution are very few, but it is estimated that c. 25% of north Indian insecticides are seriously sub-standard for one reason or another.

Added to this is the undoubted fact of evolved resistance by *H.armigera* to many of the commonly used insecticides. This has also promoted the application of increasing quantities of insecticides and mixtures. A few of these mixtures are registered and produced by reputable manufacturers, most are *ad hoc* tank mixes (often at full rates) by the farmers themselves. Proper evaluation of these mixtures has not been undertaken. Most have no enhanced efficacy over the efficacy of the best of the active ingredients alone but these applications increase the pressure for resistance selection and greatly enhance the quantity and cost of insecticides used. Even where good quality pesticides are available, farmers may be reluctant to pay the higher prices. Even with appropriate unadulterated products the quality of spray application is a further serious barrier to effective insect control.

At least thirty *Gossypium hirsutum* cotton varieties and twenty hybrids are widely planted in the Punjab. A further eight *G.arboreum* (desi) varieties are common. Farmers even plant mixtures of varieties in one field. Most are long season varieties, planted so densely and growing so tall that spray penetration to the lower canopy is very difficult. The resulting mosaic of availability of cotton at all stages of development and of susceptibility to sucking pests and bollworms over a very long season allows the build up of insect numbers to very high levels.

This is therefore a complex problem, perhaps more acute in the Punjab than in most other parts of India. 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). Following discussion with ICAR and the recognition of the presence of insecticide resistance in *H. armigera* in 1986 (Dingrha *et al.* 1988), in 1992 NRI commenced a collaborative RNRRS-funded project*, Resistance Management of* Helicoverpa armigera *in India* -R5745CB) with the ICAR and ICRISAT with 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 to:

- 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 frequencies has greatly enhanced our understanding of the dynamics of the problem in south and central India. Regular patterning of seasonal changes have become apparent (Armes et al., 1994; Armes et al., 1995). In addition we now have a much better understanding of the mechanisms underlying this resistance (West & McCaffery, 1992; Kranthi *et al*., 1997). Such data are aiding the planning and development of strategies with collaborating institutes for optimising the use of insecticides against resistant *H. armigera* populations in the southern cotton growing zone. This information was disseminated in the form of a Newsletter (*Podborer Management Newsletter*) of which two further editions have been produced by the project.

In a recent review of cotton research priorities including project activities and their impact commisioned by the Crop Protection Programme, it was stated "*It* (the preceding 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). The current project was therefore aimed at addressing IPM problems specific to the high potential cotton regions of northern India, focussing on decision processes for the rational use of agrochemicals (NRSP purpose) within an integrated cotton IPM strategy (CPP purpose). In consultation with the ICAR, Punjab Agricultural University (PAU) was chosen as the principal NARS collaborator for this project. PAU is strategically located in the Punjab cotton growing region and has a delegated responsibility for the provision of advice on all aspects of crop production and protection to the Directorate of Extension.

There was little systematic information on the status of insecticide resistance in *H. armigera* in north India, but it was known to be certainly present and probably contributing significantly to pest control problems. In 1987-1989, 3-4-fold cypermethrin resistance was recorded (Dhingra *et al.,* 1988; Mehrotra, 1990), and by 1993 20 - 37-fold cypermethrin resistance had been reported in strains from Varanasi and New Delhi (Armes *et al.,* 1996). In a parallel study, discriminating dose monitoring showed that, by 1993, cypermethrin resisitance frequencies in Haryana state were similar to those in central and southern India (Armes *et al.,* 1994). Fuller information on the level and pattern of resistance was required for the development of rational pesticide use decisions.

Whitefly damage the crop directly through feeding on the sap and excretion of sticky honeydew which promotes the growth of various fungi. On lint in particular, this is a significant economic problem. More recently, *Bemisia tabaci* has threatened the cotton crop indirectly through transmission of cotton leaf curl vir*us* (CLCuV). CLCuV is relatively new to India, first appearing in a few of the Punjab and Haryana districts bordering Pakistan in 1994 (Singh *et al.,* 1994). Since then there has been a season by season increase in the incidence of CLCuV. Few of the cotton hybrids grown in the northern zone appear to have resistance/tolerance to CLCuV (S. K. Banerjee, pers.comm.). In Pakistan there has been a major expansion in the range and importance of CLCuV to the extent that by 1993, 0.5-0.9 million hectares of cotton were affected (I. Denholm, pers. comm.). The loss attributed to ClCuV amounted to some 3% of Pakistan's GDP in 1996-97. It is a growing problem for India. In the longer term, varietal resistance (either conventionally selected or transgenically induced) must be the solution. However, much attention has been focussed on the control of the whitefly vector, despite an absence of evidence that even moderate to good levels of vector control are sufficient to curb the spread of the disease. Farmers are therefore increasing the level of chemical control operations against whiteflies.

The factors contributing to resurgence and flaring of whiteflies are well known - prolonged dry periods coupled with high temperature and high relative humidity are conducive to whitefly build-up. Indiscriminate use of broad spectrum insecticides, over-dosing with nitrogenous fertilisers and plant-plant spacing which is too close, can result in severe and economically damaging whitefly infestations (Sundaramurthy *et al*., 1990). Insecticide resistance had not been studied to see if this is a potential contributor to whitefly outbreaks in north India, but in view of the fact that resistance to a wide range of pyrethroid (3-100 fold) and organophosphate (2.7-1400 fold) insecticides is well documented in the Pakistan Punjab (Cahill *et al.,* 1994 and references therein), it was likely that insecticide resistant populations were present. For the development of a rational strategy for CLCuV containment and of whitefly control the level and prevalence of resistance needed to be established as did the role of insecticides in limiting the spread of disease.

RNRKS project R5745CB (1992-1996) addressed the practical implications of improving control of resistant *H. armigera*. The basic tenet of insecticide resistance management (IRM) is to conserve susceptibility to insecticides. Ideally IRM strategies should be preventive in order to maintain insecticide efficacy. However in most cases IRM is only adopted once insecticide resistance has become a problem, so most strategies are curative with the aim of restoring susceptibility, or at least reducing the resistance gene frequency in order to improve insecticide efficacy. The current project aimed to extend that work to north India; obtain a sufficient understanding of the whitefly insecticide resistance and disease transmission situation, to make rational recommendations and to design and test from that understanding a set of decision-making criteria for cotton pest IPM which would take account of the agricultural system within which cotton was being grown and which would enhance farmer-retained income while improving the environmental profile of cotton pest control.

Cotton is attacked by a complex of pests and for the foreseeable future, synthetic pesticides will continue to play an important role in cotton pest management. A major requirement is thus to maintain their efficacy whilst integrating their use into IPM strategies which reduce resistance selection. The decision problem faced by the farmer is how best to deploy the mix of currently available technologies against a complex of pests. The work undertaken in this project adopted a systems approach to help provide a rational basis for such decisions. The project was developed in conjunction with the ICAR and Punjab Agricultural University to address IPM problems specific to the high potential cotton regions of northern India.

A range of decision-modelling tools are available and have been used successfully in IPM decision-making (Norton and Mumford, 1993), although most examples involve individual pests (e.g. Holt *et al*., 1992). Simulation modelling of pest populations has been used widely and effectively in control tactic evaluation (Holt and Norton, 1993) but the number of parameters which need to be estimated proliferates dramatically as additional interacting species are considered.

Cotton decision systems incorporating crop growth and pest population development simulations have been developed from the early work of Baker (1972) enhanced by the use of stochastic methods based on the work of Manetsch (1976) by Gutierrez *et al.,* (1975) in California and McKinnion *et al.* in Mississippi (the Simcot and later Gossym model). These metabolic pool models have been adapted for use in other countries (Nicaragua (Gutierrez et al., 1981), Brazil (Gutierrez *et al.,* 1984), Sudan (von Arx *et al*., 1983) and Egypt (Russell and Radwan 1992)). They include work on insects of direct relevance to the Indian system ; (*B. tabaci* (von Arx *et al*., 1983); *Pectinophora gossypiella* (Gutierrez *et al.,* 1977) and diseases such as Verticillium wilt (Gutierrez *et al.,* 1983). The Gossym-Comax system for US Upland cottons includes the Comax management decision system within which the Gossym biological simulator runs. The problems of resistance management in Heliothine species have been specifically addressed in the Australian cotton system simulator (SIRATAC) (Brook and Hearn, 1983). Most practical use of the developed systems is being made in the USA and Australia, especially for water and crop termination management but also for pest management scheduling. Great simulation accuracy for particular fields is now possible but of limited use in making management recommendations where field sizes are small and agricultural practices vary over short distances. In the first major developing country use of cotton simulation modelling Russell and Radwan (1994) developed methods of running a ‘Windows style’ Arabic modification of the ‘COT’ system (Stone and Gutierrez, 1986) for representative management practices for 15 cotton districts in Egypt. Strategic use of these tools showed benefit in the provision of weekly management advice to Egyptian decision makers, with an emphasis on the use of pheromones and insecticides for control of pink bollworm (Russell *et al.,* 1995).

It was suggested that the current project should attempt to develop a similar simulator, with the aim of helping to identify agronomically suitable cotton varieties and practices and to help schedule pest management operations, although it was appreciated that the multivoltine and polyphagus *H.armigera* is a much more difficult pest to model usefully than the effectively monophagus and bivoltine pink bollworm. It was also appreciated that Indian cotton production has a far more complex social context than that in Egypt (where the MOA makes decisions centrally and applies many cotton management inputs directly). Modification of existing cost/benefit prediction models (e.g. Sterling, 1993) to adequately simulate the growth of local cotton varieties under Indian conditions was suggested as the most efficient route for the development of a useful model in a short time-frame. Considerable expansion of existing pest management routines were required to cover key north Indian species. The intention was to provide decision trees produced from the analysis of the socio-economic and cost/benefit analysis of insecticide, fertiliser and other inputs. These would then be used to generate management scenarios which would be iteratively tested on the customised system to produce minimum input, robust recommendations for crop management under a variety of north Indian biological and financial constraints. These simulations would then inform the design of appropriate IPM systems for field demonstration.

As explained below, it rapidly become evident that this component of the project was unlikely to yield results which would be significantly useful for pest management scheduling over any considerable area owing to the wide mixture of cotton species, varieties, planting dates and agronomic practices used in the Indian Punjab. Its potential providing support for proposals to change the system, was by overtaken by events, with both farmers and the state agricultural system eager to adopt appropriate IRM practices right from the first project season, and the project re-focussed on larger-scale application of the results of research work to date.

3 Project purpose

Specifically the project addressed twin purposes.

- For the **Natural Resources Systems Programme** the purpose was 'R*ational use of agrochemicals developed and promoted'* contributing to the goal '*System commodity production increased by optimising inputs and outputs'.*

- For the **Crop Protection Programme** the purpose was *'Integrated cotton pest managmeent needs assessed and strategies developed and promoted',* contributing to the goal *'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 temporal dynamics of the pest complex, the project aimed to develop a rational, systems, approach to improve IPM decision making for irrigated cotton in northern India. This information developed was to be used to demonstrate a practical IPM system for irrigated cotton with emphasis on sustainable management of insecticide resistant pests while maintaining or enhancing farmer incomes and improving the environmental impact of cotton growing in the Indian Punjab.

A systems approach was adopted to help provide a rational solution to the pest management decisions faced by farmers growing irrigated cotton in north India. By the end of the two and a half year project period, the project aimed to have:

- undertaken a thorough socio-economic study of cotton farmers in the Punjab and of the factors affecting their pest control decisions;
- identified the main effects of macroeconomic and sectoral policies and of the institutional framework on the choice and availability of pest control methods in cotton;
- identified the key factors for improving the safety and efficiency of pesticide use and application in cotton;
- developed an IPM decision model for the irrigated cotton cropping system in north India;
- through researcher-managed on-farm trials, tested recommendations for a safe, effective and economically viable cotton IPM strategy;
- identified the status and dynamics of insecticide resistance in *H. armigera* and *B. tabaci* in the Punjab and the data used in pesticide use decisions;
- undertaken field studies and surveys to determine the importance and likely spread of CLCuV and identified strategies for its containment and management.

The results of the work were to be disseminated through ICAR and PAU reports, farmers' field days and extension activities, training in insecticide resistance methodologies, bioassay and insecticide toxicology, project meetings, workshops and newsletters. Involvement in the All India Coordinated Cotton Improvement Project, the ICAR *Heliothis* Network Project and the Insecticide Resistance Action Committee provided opportunities and venues for the exposure of the project results. The results were also promulgated at national and international conferences and in journal publications.

4 Research activities

Staff inputs
To implement the above project aims, a team comprising an appropriate skill mix of entomologists, a spray application specialist and socio-economists was assembled. Inputs were made as per the project memorandum and its amendments.

The project was managed from NRI by Dr D. Russell of the Pest Management Department supported by Mr J. Cooper as the insecticide applications specialist. Dr Russell made five visits to the Punjab and Mr Cooper, three.

The PAU entomological team was led by Dr Joginder Singh, the pre-emminent cotton pest management specialist in the Punjab. Dr Singh was supported in the field work by Dr A.S.Sohi (Jnr) and Dr D.S.Brar, also of the Entomology Department at PAU. They in turn were supported by two project-funded Research Associates for the field work and up to 30 field IPM promotion staff, particularly in the final year of the project.

The measurement of insecticide resistance in *H. armigera* was undertaken by Dr S.K. Kapoor and of whiteflies by Dr Darshan Singh, both of the Entomology Department at PAU. This laboratory work was supported by project –funded research associates N.Sharma and P.Sarao. The work on whitefly resistance on CLCuV containment was supported by three visits to the Punjab by Dr I. Denholm of Rothamsted Agricultural Research Station, UK, with some input into the design and analysis of results by Dr M.Cahill, also of Rothamsted.

Training visits with reference to the whitefly insecticide resistance work (Rothamsted and NRI) were made by Dr D. Singh and Ms S.Sharma. Dr J.Singh visited NRI in connection with the 'Resistance '97' meeting held at Rothamsted.

Dr D. Overfield of NRI's Social Sciences Department undertook the responsibility for leading the socio-economic input, working with Dr R.S. Malhan of PAU's Department of Agricultural Economics (as a project-funded Research Associate) and Dr P. Elangovan of the Economics Department of Tamil Nadu Agricultural University who undertook the comparative study of adoption and sustainability of the IRM practices in the Punjab and in the three southern states in which the sister project R5745CB was operating (under a project ammendment). Dr Overfield made the scheduled three visits to PAU.

Equipment provided
As foreseen in the proposal, it was necessary to strengthen PAU's capacity to undertake the resistance measurement work (particularly for whiteflies, a new area of study for PAU) and to provide mobility for project staff to undertake supervision of the farmer participatory IPM work. To this end a refrigerator, a microbalance, incubator, microapplicators, Hamilton syringes, ELISA assay unit, air-conditioning units and insect rearing equipment were provided to the Entomology Department PAU. To support the field collection of insects and the supervision of the field testing of the developed IPM/IRM strategy a local jeep (Tata Sumo –through ICRISAT) and two motor bikes were purchased for the use of project staff. A PC with appropriate software, scanning and printing ability was provided for Polo analysis of resistance data and the compilation of lab and field data and the production of reports.

RESEARCH ACTIVITIES

The following activities, associated with project outputs, were specified in the project memorandum.

Systems components

- Socio-economic survey
- Computerised IPM decision tool
- Study of farmers' pest management decision making
- Study of the effects of the cotton sector environment on IPM
- Study of safety and efficacy of insecticide use
- Report on CLCuV in north Indian cotton and make recommendations for its containment

IPM components

- Field trials of spray application methods
- Testing developed IPM/IRM recommendations on-farm
- Assess insecticide resistance levels in the key pests, *H. armigera* and *B. tabaci*:

Systems components

1. *Socio-economic survey*: A socio-economic survey was undertaken to classify the main types of cotton farmers within the study area selected by PAU (for example, large/small, contract/private, monocrop/mixed crop, main source of livelihood/sideline, men/women etc.). This typology was used in the other activities to ensure that different farming practices and constraints are identified correctly for different farmers. This study was undertaken by the NRI social scientist Dr Overfield in conjunction with a project recruited PAU socio-economist, Dr Malhan and the PAU project leader, Dr Joginder Singh. (Malhan and Singh, 1998)

2. *Computerised IPM decision tool*: At the time of preparing the project proposal it was intended to develop a computerised IPM decision model for irrigated cotton in the Punjab, probably based on a biological simulation model of cotton growth and of pest populations. Two approaches were chosen, an experimental layout designed on the PAU farm with appropriate meteorological equipment, brought in from ICRISAT and NRI (already available from earlier projects) and staff identified for the work. However, as Dr Russell became familiar with the cotton agronomy of north India, it quickly became apparent that the huge range of cotton varieties, species and agronomic practices would render any biological model predicated on the growth of particular varieties (with their own growth habits, fruiting patterns etc) almost useless for practical decision making over any significant area. The regional resources of data collection, computer analysis and state control of pest management practices which had proved successful in the earlier project undertaken by Dr Russell in Egypt (Russell and Radwan, 1992, 1993, Russell, 1995) are absent in the Indian Punjab and despite considerable research interest at PAU and CICR Nagpur, it was apparent that there was no uptake pathway for a developed system at this time. The studies of the cotton sector and of farmers' practices quickly revealed where the most important inadequacies of the system lay. Given the crisis nature of the problem, the early success of the IRM programme in all the states in which it was trialled, and the willingness of the state government to attempt to implement these practices, the project re-focussed very quickly on the measurement of the basic underlying biological parameters and refinement and implementation of the IRM strategy for north Indian conditions and a computer tool was not developed.

3. *Study of farmers' pest management decision making:* A review of the factors affecting farmers' decision making on the rational use of agrochemicals and the likely uptake of the developed sustainable strategy for pest control was undertaken as part of a study of four cotton states by Dr Elangovan of Tamil Nadu University, working with Dr Overfield of NRI (Elangovan, 1998 – project report and Elangovan *et al*., 1999).

4. *Study of the effects of the cotton sector environment on IPM*: An investigation was undertaken by Dr Malhan of PAU of the policy and institutional factors which would encourage the rational use of pest control measures in cotton production (Malhan and Singh – final version 1999). This led to policy recommendations made at a variety of state and national fora.

5. *Study of safety and efficacy of insecticide use*: The key factors for improving the safety and efficiency of pesticide use were examined by the NRI application expert and PAU cotton pest management specialist. Recommendations on safer spray application technologies, giving cost-effective benefits to producers, reduced potential hazards to farmers and the environment were promulgated through farmer and extension personnel training sessions and compiled in a pesticide use manual for the Punjab (Cooper *et al.* 1997).

IPM components

6. *Field trials of spray application methods*: Tests were undertaken on the university farm by PAU staff supported by Mr Cooper, of the spray deposition pattern of currently available hand held and tractor mounted equipment and of possible new equipment (J.Singh *et al.* 1997, 1999). A recently introduced tractor-mounted air blast sprayer was assessed, but deemed to be unsuitable because it could only work effectively at 90^o to the prevailing wind direction whereas the direction of travel through the crop is dictated by row orientation.

7. Testing developed IPM/IRM recommendations on-farm: Drawing on the detailed laboratory and field entomological and socio-economic work and with the background of research and testing of viable IRM technologies from the preceding project, an effective strategy for integrated pest management involving varietal and agronomic components as well as optimal usage of pest management interventions was developed and tested on-farm. There were twenty participants in the first project season. This was so successful and attracted such interest from farmers and the Punjab government that it was adopted as the core strategy for the Punjab Chief Minister's Initiative to implement IPM in 11 contiguous villages in the Lumbi Block of Muktsor District in the 1998 cotton season. This involved convincing participating farmers of the value of the proposed measures, supporting their implementation of the programme and helping to orchestrate non–project inputs. Project staff were the key scientific resource for this work and the project provided IPM scouts and support staff for each of the villages in the 1998 cotton season.

8. Assess insecticide resistance levels in the key pests, H. armigera *and* B. tabaci*:* Routine monitoring of resistance to a range of pyrethroid, organophosphate, carbamate and cyclodiene insecticides by topical application of larvae was undertaken by Dr Kapoor of PAU Entomology Departemnt and the results fed into the IPM strategy. A whitefly resistance monitoring (leaf-dip method) and esterase polymorphism determination facility was set up at PAU and, for the first time in the Punjab, resistance levels to pyrethroids, organophosphates, cyclodienes, bifenthrin and the novel neonicotinyl, imidacloprid were assayed from a range of populations across the cotton belt.

9. *Report on CLCuV in north Indian cotton and make recommendations for its containment*: The routine surveying of CLCuV prevalence throughout the Punjab by the project team was supported by the Cotton Corporation of India. This allowed DFID resources to be utilised in extensive screen house experiments to identify tolerant/resistant germplasm, alternative weed and crop hosts of CLCuV in India and to experimentally ascertain both the efficacy of the commonly used insecticides against the vector and, critically their efficacy in suppressing disease transmission. The results of this work were formulated into a CLCuV containment policy accepted for implementation from the 1999 season by the Agricultural Directors of the three northern states of Rajistan, Haryana and Punjab.

Project amendments
Additional outputs in support of the above were provided under programme development funds (Dec 1996) and project amendments.

The programme development funds allowed:

- the project leader and NRI socio-economist to discuss the project with the DFID NR advisor in New Delhi (Mike Wilson), to explore the prospects for uptake pathways for the project outputs and to commence the investigation of the institutional and community structures favouring or holding back IPM implementation in the Punjab. This took place in Dec 1996 and provided information in support of the approval of both the NRSP and CPP components in Jan 1997.

The project amendments provided for:

- Attendance of the project team leader from NRI and Dr A.S.Sohi from the PAU team at the World Cotton Research Conference II in Greece in 1998. Three papers deriving in whole or in part from the northern project were presented (Regupathy *et al*. 1998, Russell *et al.,* 1998 and Singh *et al.,* 1998).

- Support for the team of 33 field workers required for the unforeseen expansion of the IRM field demonstrations to 11 villages in the 1998-9 cotton season.

- Support for a socio-economist from Tamil Nadu Agricultural University to evaluate the extent of the adoption of the project recommendations from the current project and the concurrent work being undertaken in dry-land cotton under R6734. As agreed, a project report (Elangovan *et al.* 1999) and a journal article (Elangovan *et al*. 1999 submitted) resulted.

- The Reading University statistical service provided the requested advice on analysis of the socio-economic data to Dr Overfield, which informed the production of the publications on this aspect of the project.

- The project leader attended the meeting on national IPM priorities in Ludhiana (28-29 Nov 1998) with seven papers resulting (see publications section).

- The Central Institute for Cotton Research produced and has sold at recovery price, 2000 copies of the English and local languages project colour pamphlet on cotton IPM as agreed (Insect Pest Control in Cotton; Dec 1998 edn.).

- Ms Iyengar of Greenwich University provided the analysis of environmental impacts of the project as requested. 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 R6734.

Dissemination of outputs

10. *Dissemination*: Peer-reviewed papers have been produced for biological, development and socio-economic journals (7) and international (3), national conference presentations (3) and meeting papers (15) have been produced on CLCuV, pesticide regulation issues, whitefly resistance patterns, whitefly polymorphism, bollworm resistance, IPM strategies and the environmental impact of those strategies. A pesticide application manual and local language IPM guidance brochures for farmers have been produced. Farmer pesticide application training days were held and the developed IPM principles promoted at farmers' field days and in newspaper and radio articles, in addition to the village level training provided in the participating villages throughout the project.

Of particular importance were the presentations by NRI and PAU staff at the final workshop of the *ICAR Heliothis Network Research Project in June 1998,* at which national recommendations were formulated for all crops. Project outputs formed the basis for the cotton policy. The second significant meeting was the National Seminar *on 'Critical issues of IPM in the changing agricultural scenario of India'* in Nov 1999. Project staff provided eight papers on various aspects of irrigated cotton IPM/IRM and associated topics. Recommendations from the meeting have informed the policy of the Indian Plant Protection

Advisor. In particular the views presented on the role of pyrethroids and of insecticide mixtures in cotton pest management have been very influential.

5 Outputs

The agreed outputs were:

- Understanding of pest management constraints at institutional, industry and farmer level.
- Decision system with underlying biological model capable of running scenarios and producing IPM recommendations.
- Report on recommendations for rational pesticide use (including application) in cotton production in the Punjab.
- Report on socio-economic status of cotton production in north India and possible uptake pathways for IPM technologies.
- Insecticide resistance monitoring data for *H. armigera* and *B. tabaci* available.
- Report on the status of CLCuV in north India.
- Information on current and improved decision making processes for cotton pest management applicable to irrigated cotton in north India.
- On-farm demonstration of an effective cotton IPM strategy.
- Research papers, bulletins, handbook and newsletters available.

Understanding of pest management constraints at institutional, industry and farmer level.

Studies of the cotton sector and farmer profiles were undertaken by Dr R.S. Malhan, the PAU project socio-economist. The results are summarised in the project report (final version - Malhan and Singh, 1999) and in a paper 'The Green Revolution, changing farming systems and declining cotton yields in the Indian Punjab' by Overfield and Malhan (submitted).

The irrigated northern zone of Punjab, Haryana and Rajisthan was responsible for 22% of India's cotton production in 1996-7 with average cotton yields of c.400 Kg/ha, far higher than the national average of 279 Kg/ha. Studies of 260 farm households in 13 villages in the Punjab cotton belt showed that gross cotton yields and gross revenues per hectare have been declining across the belt by 60-70% between 1994 and 1997. Over the same period insecticide use has increased by 22% and the cost of spraying has increased by 50%. As a result, net profit has declined to the point at which most farmers are making a loss on cotton. There are biological reasons for this – over the last two years unseasonable rains and exceptionally high outbreaks of the bollworm *H. armigera* and the whitefly *B. tabaci* have contributed. Heavy and late rains in September and October were also a factor in the extremely poor yields in 1997 (142 Kg lint/ha in the Punjab, the lowest for over 30 years), though both the direct effect on fruit shedding and the indirect effect of enhancing bollworm populations at this critical time in the season.

Social factors also play their part through the intensification of production, the move to irrigation and the use of input levels which damage both groundwater and the agricultural system. These can be seen as concomitants of the Green Revolution, which, in the Punjab, does not seem to have brought about a sustainable general increase in agricultural productivity and increase in incomes, partly due to the trend to increasing concentration of resources. Although farmers' improved yields were correlated with educational backgrounds, the clearest correlation was with the quantity of insecticide used. (Interestingly, contact with the Agricultural Extension System was shown to have no, or even a slight negative impact on pesticide use) The yield increase with increased insecticide use did not, however, translate into higher profit margins because of the costs of these inputs. Plant protection costs were 54% of growing costs. Production elasticities of conventional insecticides were not significant in all categories of farm except those of medium size. Analysis of the yield data suggested that yield peaked at around 9-10 sprays per season and that profitability was maximised at around 8 applications (although this may be substantially improved on by better targeting of more appropriate materials). Nonetheless farmers applied on average 12 sprays (15 in villages more removed from project operations), many of these mixtures of different active ingredients at significantly enhanced cost. Average costs were such that, even ignoring opportunity costs, the surveyed growers made an average loss of c.2,400 Rs/ha in 1998. Agricultural advice is strongly concentrated with the commission agents, who are also the vendors, usually on credit, of insecticide which was often poorly formulated. Farmers were 'panic spraying' as soon as any caterpillars or whitefly were found in the field and frequently with inappropriate materials. There was a clear need for a simple system of protecting yields through the rational use of appropriate insecticides, applied only when pest numbers exceeded some pre-determined threshold.

Decision system with underlying biological model capable of running scenarios and producing IPM recommendations.

As explained above, work to develop the computerised simulation model was not undertaken. The decision management system developed and utilised was based on the experience gained in 1993-6 in the preceding CPP project and the very considerable experience of the PAU staff, and refined by the experiences gained with farmers in the 1997 season. This is dealt with in more detail below.

Report on recommendations for rational pesticide use (including application) in cotton production in the Punjab.

Experimental examination of the efficacy of conventional spray equipment (manual knapsack, power knapsack and various tractor mounted equipment) was undertaken on the PAU farm in the 1997 and 1998 seasons (J.Singh et al 1997, and 1999 – project reports). The ability of equipment to deposit insecticide on the underside of leaves, where whitefly congregate, was of particular importance. From the middle of the cotton season onwards, conventional knapsack spraying equipment is only adequate in modern, short-stature, open architecture varieties. However, even the better types of standard tractor mounted, boom, sprayers provide inadequate underleaf converage in the tall, dense canopies of many of the cotton varieties grown in the Punjab. The newer, but very expensive, airblast sprayers can make some improvement in canopy penetration under ideal conditions but are not recommended because they rely on being used at 90^{o} to the prevailing wind direction which the row orientation prevents this for much of the time. Better spray distribution could be achieved with better engineered sprayers, but changes in crop spacing and architecture which allow the drops to reach all parts of the plants more important. Discussions took place with the main Indian equipment manufacturer Aspee on provision of improved nozzles and other components.

In the participatory trials and demonstrations, farmers were shown how to maintain, calibrate and operate the standard equipment to maximum advantage and in the safest manner possible. Where necessary better spray nozzles were made available.

A comprehensive manual for appropriate pesticide application user safety, equipment selection and maintenance, methods and choice of pesticide and rates of application was developed for southern and central India by *Cooper et al*., (1998) and modified for use in the Punjab by Singh and Cooper (1998). This was used as a basis for training farmers and field staff (33 in 1998) who implemented the work in Gobindgarh and Tarkanwala in 1997 and the 11 villages of the Lumbi block in 1998.

An analysis of the role of chemicals in pest management in cotton in northern India was produced by J.Singh *et al.* (1998c). The problems with insecticide quality control were addressed in the paper by Bakhetia *et al.* (1998a), and with pesticide mixtures by J.Singh et al. (1998 b).

Report on socio-economic status of cotton production in north India and possible uptake pathways for IPM technologies.

An early rapid rural appraisal of the cotton system carried out under programme development funding at the end of 1996 by Dr Overfield, showed the crop production and protection practices to be surprisingly scale-neutral except for spray mechanisation which was understandably more common amongst larger farmers. The major constraints identified were, in order of importance:

- Pests;
- Poor quality of pest control chemicals;
- Insecticide resistance;
- Too low a proportion of the seeds used being certified;
- Poor cotton prices;
- The high level of indebtedness;

Impacting on world cotton prices was beyond the scope of the project. Strong efforts were made to support the use and promotion of certified cotton seed but it must be said that the current certification system can produce only about 20% of the region's cotton seed needs and some of the most popular, versatile, and best yielding material is produced only in the uncertified private sector. The high level of indebtedness is in quite major part related to the extent of the expenditure on crop protection (mostly on credit and in a crop which has been at best marginally profitable in recent years).

As indicated above, the question of enhancing pesticide quality is bedeviled by the need for importers to provide 50% of the active ingredient to local formulators who (having no development, testing or registration costs to recover) can then undercut the original manufacturers with much cheaper, and often very poorly formulated, generic materials. The national pesticide quality control system allows for the testing of materials taken from dealers shelves, but corruption in the system and the fact that the dealer is able to supply a second sample for testing later has resulted in very few successful prosecutions.

PAU is well aware of the problem but as only certified laboratories can present evidence to the regulatory authorities and as this is an extremely litigious area, practical steps could not be taken to enhance pesticide quality generally. However, active discussions were held with the pesticide dealers in the project villages in 1997 to encourage then to stock and recommend appropriate chemicals, providing alternative choices wherever possible. In 1998, as part of the Punjab Chief Minister's initiative, it was agreed that the Cotton Corporation of India (CCI) would make the recommended good quality chemicals available at cost to farmers in the participating villages. However, most farmers purchase insecticides on a credit system (which is outside CCI's remit to provide), normally from the same source as they use for all their domestic credit. These ties are strong and the credit provider is not to be lightly crossed. A state bank credit system was put in place whereby a credit slip was issued to farmers for redemption against cotton inputs (feltiliser and pesticide). The government company, MarkFed set up pesticide outlets in the Lumbi block specifically to provide these quality inputs under credit.

The system did not work perfectly. Some farmers were too closely tied to their normal credit provider to feel able to change to the MarkFed stores and, in many cases, those operating the MarkFed stores continued to give poor advice and to sell farmers chemicals with the largest margins, rather than those recommended by the project. Nonetheless, a certain level of adoption of appropriate chemicals was achieved.

Supported by Dr Overfield the detailed descriptive work on the economic status of cotton and the cotton-producing farmers was carried out by Dr R.S. Malhan of PAU as described above. Dr Elangovan of Tamil Nadu Agricultural University 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 (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 Punjab study ,at the end of the 1998 cotton season, used 30 randomly selected farmers from eight of the project villages for data collection by interview.

The awareness and adoption component of the study looked at 19 factors. Of these awareness and adoption of correct insecticide timing, dose and methods of spraying were appreciated and universally applied. 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. 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 in for the very large number of farmers in these villages. In comparison, working with a smaller number of farmers in the Palani area of

Tamil Nadu, where project-supported demonstrations were in their second year, awareness and adoption of almost all components was very high and adoption (again according to farmer interviews) was 93-100%. Although the extension system was undoubtedly over-stretched and less effective when compared to that run by the PAU team itself in the Punjab trial, this does highlight the need for training to continue over more than one cotton season.

For the Punjab the measured determinants of adoption included in the econometric model (see Elangovan and Overfield, 1999 for details) 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.

The model explained 82% of the variation in the adoption of the project promoted technology. However, of the determinants, only farmer education level (and more importantly the general education level in the whole family) and the advice of insecticide sales representatives, correlated positively with adoption of the project practices. Given that affecting the general level of education is beyond the capacity of projects such as this, these findings vindicated the effort expended in meeting with insecticide dealers networks and individual dealers in an effort to explain the principles and benefits (including to the dealers) of rational pesticide management. Advice from fellow farmers was a positive determinant, supporting the view that it is important to stimulate participation from as high a proportion of the community as possible to ensure that changes in practice are sustainable.

Unexpectedly the area of land owned was negatively correlated with adoption, possibly because those with larger commercial farms did not themselves carry out the crop management practices. Even more unexpectedly, regular TV and Radio advice was also (though not significantly) negatively correlated with adoption. The reasons for this are not clear.

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 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.

Insecticide resistance monitoring data for *H. armigera* and *B. tabaci* available.

American bollworm - H.armigera
Pyrethroids and certain organophosphates (quinalphos, chlorpyriphos, monocrotophos and acephate) are the most popular chemicals used for bollworm control in north India. Using standard leaf-dip and topical application methods, Dr S.K.Kapoor of PAU Entomology Department monitored levels of resistance to a range of insecticides used for bollworm control across the seasons in four cotton growing districts of the Punjab. Cypermethrin and fenvalerate were chosen as representative pyrethroids, quinalphos as the most popular organophosphate, endosulfan as the sole major cyclodiene and methomyl as the only widely used carbamate. In all cases there was an increase in resistance towards the end of the cotton season. Fenvalerate resistance was highest at 65-75% of larvae tested surviving a discriminating dose of insecticide which would be expected to kill susceptible insects. By the end of the season cypermethrin was almost as strongly resisted at c.60%. Quinalphos showed 20-40% resistance and endosulfan 15-30%, roughly the same as for methomyl. (Kapoor in *Podborer newsletter 9,* and Kapoor, (1998)).

These results bring the Punjab broadly in line with the rest of India after a number of years in which resistance to the pyrethroids in particular appeared to be lower in the North. Resistance to pyrethroids in now so severe as to undermine their efficacy and farmers are increasing dosages and resorting to chemical mixtures in attempts to gain control of *H.armigera* larvae.

Whitefly - Bemisia tabaci
The work at PAU on *B. tabaci* insecticide resistance using the standard leaf-dip bioassay for foliar insecticides and a petiole-dip method for systemic insecticides showed that significant resistance was present in the cotton belt to the bollworm control chemicals, oxydemeton methyl, dimethoate, acephate and chlorpyriphos. Moderate levels of resistance were recorded for monocrotophos and quinalphos. Resistance was found to increase as the cotton season progressed. However, all whitefly populations remained susceptible to the major whitefly control chemicals, triazophos, bifenthrin and ethion and to the new systemic, imidocloprid and to the widely used bollworm chemicals endosulfan and profenophos. These results were incorporated into the 'best-bet' cotton IPM demonstrations, and took into account the effect of profenophos in causing resurgance in whitefly (see below).

Polyacrilamide gel electrophoresis (PAGE) analysis showed differences in esterase banding patterns between populations within the cotton belt, suggesting that local spraying histories affect the resistance pattern.

These results are presented in D.Singh (1998) and D. Singh *et al.* (1998 a and b, 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 (from Russell *et al.* 1999)

* 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

Pest Species	**Insecticide**	**North**	**Central**	**South**
American bollworm	Pyrethroids	v.high	v.high	High
(H.armigera)	Quinalphos	Mod.	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	-

Cross resistance and resistance stability

As indicated above, there is evidence (but requiring further work) for cross resistance between quinalphos and methomyl for all the lepidoptera. Spotted bollworm *E. vitella* and cotton leafworm *S. litura* appear to show quinalphos/ monocrotophos cross resistance, and *E. vitella* alone shows monocrotophos/ methomyl resistance. For *H.armigera*, the current data suggest additional endosulfan/ quinalphos cross resistance. Resistance to pyrethroids can also be correlated with resistance to certain organophosphates and indeed to carbamates and endosulfan. However, the high pyrethroid resistance levels throughout the country make disentangling these relationships difficult.

In *H. armigera,* the only species so far tested, 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 (1996), McCaffery *et al.,* (1998) and by Kranthi *et al*., (1997, 1999 and in press).

Report on the status of CLCuV in north India.
CLCuV was first detected in India in Sri Ganganagar in Rajisthan in 1993 and from the Punjab in 1994. It is now present in the entire northern zone with losses depending on the growth stage at which the plant was first infected by the disease (earlier infection, higher losses). Boll number reduction on infected plants thus ranged from 15 to 87% and boll weight reduction from 0% to 39%. Seed cotton yield was reduced by 11% when the disease is confined to the apical leaves, 58% when it is widespread in the upper plant canopy and 69% when it is present in both the upper and lower canopies. Early infection gives an average yield loss of 92%.

The whitefly vector is active throughout the year on a wide range of crop and non-crop host plants. A number of weed and other non-crop hosts were demonstrated as carriers of CLCuV. Back transmission was demonstrated in *Sida* spp., *Abutilon indicum and Xanthium strumarium,* but other malvaceous plants and plants of other families are likely also to be hosts (tomato, okra (*Abelmoscus esculentis*), *Hibiscus rosasienensis*, *Althea rosea*, *Ageratum conizoides* and *Datura* sp.) Whitefly move on to cotton at the cotyledon stage and numbers increase throughout the season. The most dramatic increases occur from October onwards when the crop begins to senesce, but populations earlier in the season are more than adequate for disease transmission to occur

Screen cage trails showed that the standard whitefly control chemicals (oxydemeton methyl, triazophos, dimethoate, ethion and diafenthiuron) and the new chloronicotinyl, imidocloprid, although effective in killing whiteflies, could not do so sufficiently rapidly to have a significant effect in preventing CLCuV transmission from viruliferous whiteflies. In consequence, the recommended control measures are partly cultural (weed clearance, destruction of alternate hosts, rogueing infected plants) and partly rely on the use of resistant/tolerant cultivars. Amongst these, all *Gossypium arboreum* (desi) cotton tested so far is resistant. The *G.hirsutum* varieties LRK 516, LRK 861, CSH 15, CSH 19 and the *G.hirsutum* hybrids LHH 144, Kasturi 2 and Kasturi 18 appear to be resistance to CLCuV. *G.hirsutum* varieties, H 1180, HS-90-80, LRA 5166, RS 875, RS 2013 and Kanchana are tolerant to CLCuV, showing only mild symptoms. Steps are now being taken across the northern cotton zone to bulk-up appropriate resistant material. In the interim, available seed from popular tolerant varieties (esp. LRA 5166) is being used.

Amongst the available insecticides, triazophos and ethion proved the most effective in curbing whitefly numbers. In field studies acephate, quinalphos, and profenophos amongst the organophosphate insecticides and alphamethrin and cypermethrin amongst the pyrethroids, caused resurgance of whiteflies and they are now not recommended for use when whiteflies are present (although as these are important bollworm control chemicals, this advice is not proving easy for farmers to follow). The above data and recommendations are contained in J.Singh *et al.* (1998) and have been widely promulgated at meetings within India (e.g. D.Singh *et al.* 1998).

Information on current and improved decision making processes for cotton pest management applicable to irrigated cotton in north India.

The studies by Overfield and Malhan (1999), Malhan and Singh (1998) and Elangovan *et al.* (1999) reported the extent of spraying, the materials used and the source of decision making advice. As in the rest of India no farmers were using any type of structured pest scouting, nor were applications made when particular insects reached particular threshold numbers. Rather, spraying was undertaken when insects were seen in the field, or indeed when neighbouring farmers were seen to spray. On the other hand farmers could identify the major pests, whitefly and bollworm and many could distinguish the bollworm species (pink (*Pectinophora gossypiella*), spiny/spotted (*Earias insulana/ vitella*) and the American bollworm.

Knowledge of which materials to spray and at what rates came largely from experience and from the advice of the pesticide dealers, although the radio and TV programmes containing advice to farmers were also heeded. It was very clear that the state agricultural extension service was very poorly known to farmers. Very few farmers indeed had ever been visited and farmer respect for extension service staff was very low. By contrast, many farmers had attended PAU farmer field days, had sought advice from PAU staff on particular issues and the PAU handbook of agricultural practices was widely known.

Nonetheless, in their report on the field work, J.Singh et al. (1998c) identify 40 insecticide tank mixes used by farmers in addition to the three registered mixtures (‘Spark’, ‘Polytrin-C’ and ‘Neural-D’). The average number of insecticide applications per season was around 15 in non-project villages, probably close to twice the optimal number.

A number of factors contributed to the development of the recommended pesticide use strategy. Identifying the resistance profiles of the key pests and understanding the mechanisms of resistance in the preceding project were important. The information on which chemistries flared or caused resurgence of other pests was also taken into account. Consideration was given to alternating chemical groupings in successive spray rounds in order to minimise resistance development.

It was also clear that delaying the foliar application of any broad-spectrum materials for as long as possible would be essential for preserving the beneficial insect fauna present in the field. As a consequence (and based on experience gained in the southern project), use of the chloronicitinyl imidocloprid as a seed dressing with systemic action was recommended. This compound was undergoing registration trials in India at the time but Bayer provided small quantities on a trial basis. This material was very effective against early season sucking pests and enables foliar pesticide applications to be delayed until sixty days or more after planting.

The full agronomic details of the recommended IPM practices cover soil fertility, agronomy, varietal selection, plant spacing, irrigation and fertilisation, pest and disease scouting practices etc. These, along with the recommended spraying practices are given in the PAU Handbook for farmers. Significant changes to this advice requires the agreement of a number of committees, must be based on field trials, and therefore has a long lead time. Nevertheless, where significant refinements were possible within that framework, they were recommended to farmers. A number of extension documents were produced, including a *'Do's and Donts'* list from PAU.

The simplest codification is given in the project produced CICR Technical Bulletin No. 1/1999 in the form of a chart of dates, crop stages, associated pests, economic thresholds and management options. A version (minus the graphics) is shown in Table 2 below.

Table 2: Summary recommendations for cotton pest control in irrigated cotton in N.India 1998.

	May-June	**July**	**August**	**September**	**October**	**November**
Insect pests	Aphids	Aphids Thrips	Pink bollworm Whiteflies Jassids	*Helicoverpa* Pink bollworm Whiteflies	Pink bollworm Helicoverpa	Red cotton bug
Economic threshold		Jassids – 2/leaf Thrips – 50/leaf	Whitefly – 10 flies/leaf Pink bollworm – 5% damaged fruiting parts	*Helicoverpa* –20larvae/20 plants	10% damaged bolls	
Management options	Grow jassid resistance genotypes	Resistant genotypes, Endosulfan (emergency option)	*Trichogramma* /HaNPV	Endosulfan/ Pyrethroid	Quinalphos/ Chlorpyriphos	Methomyl/ Thiodicarb
Crop stage	Vegetative	Vegetative	Squares, Flowers and small bolls	Squares, flowers and bolls	Squares, flowers and bolls	Bolls
Crop age	0-30 days	30-60 days	60-90 days	90-120 days	120-150 days	150-180 days

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These brochures were popular with farmers and effective in passing a simplified message. Tables provided rather more detail, with a choice of materials given wherever possible.

Table 3 Insecticide Control Schedule: (simplified) for the 'best-bet' trials 1987-8 (need-based; alternatives for a given spray round are in order of preference). Insecticides only to be used where scouting showed them to be necessary.

Spray round	**Pest**	**Common name**	**Total dose per acre**
Pre-planting	Sucking pests	Imidocloprid	5.25g
		Endosulfan 35EC	600 ml
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	Cypermethrin 25 EC	210ml
		Fenvalerate 20 EC	220ml
		Deltamethrin 2.8 EC	220ml
		Lambda cyhalothrin	180ml
5	3rd bollworms	Quinalphos 25 EC	800ml
		Chlorpyrifos 20EC	800ml
6	Last bollworms	Carbaryl 50 WP	800g
		Thiodicarb 75 WP	300g
If present and over threshold at any time			
	Whitefly	Triazophos 40 EC	450ml
	Mites	Ethion 50 EC	400ml

Note: pyrethroids are still very effective against pink bollworm and spiny/spotted bollworm complex.

On-farm demonstration of an effective cotton IPM/IRM strategy.

The strategy developed above was extended to 20 farmers in each of the two villages of Gobindgarh (Abohar) and Tarkanwalla in the Ferozpur district of the Punjab cotton belt in the 1997 season. The PAU team selected collaborating farmers were in each of the two villages, based on their experience in the region and their belief that these would be 'lead farmers' for others in the district. It was intended to use these as 'core' villages for an expansion into fully village participatory demonstrations in the same area in the 1998 season. In the event, the destruction of the crop in Tarkanwalla by heavy rains in mid-season and the desire of the Punjab Chief Minister to focus the 1998 programme in an 11 village cluster in the Lumbi block in Muktsor district, changed this plan. Although having the benefit of expanding the area of involvement greatly, the element of continuity was lost and the full benefits were not immediately obtained by the >1,000 farmers there.

The integration of project recommendations on pesticide use into farming practicies is summarised in J.Singh *et al*., (1998c). Project farmers were actively trained in these principles by PAU and NRI staff. Junior staff were based in the villages to support the farmers in the development and use of pest and disease scouting practices. These practices were also promulgated through a series of newspaper articles and news releases, and articles on local radio and television at eight points in the cotton season. These were widely effective in influencing cotton growers (the 1998 schedule is summarised in Appendix III of J. Singh *et al.* (1998c))

As indicated above, 1997-8 was probably the worst year on record for both whiteflies and *Helicoverpa* right across the Indian and Pakistan Punjab and the total yield across the state was reduced by 50% compared with a normal year. This made it difficult to focus farmers on delaying early insecticide use and restraining themselves in the frequency with which they sprayed. Nontheless the results below clearly show useful impact.

Table 4: Comparison of results from 20 farmers participating in the 1997 'Best-bet' trials and those of 20 matched non-participating 'control' farmers.

Site	**No. of Spray rounds**		**Yield increase/ha**	**Net profit increase/ha**
	Particip.	**Non-particip.**		
Gobindgarh	7.0	15.7	100%	Rs 9,563*

* *Non-participating farmers made a significant loss.*

The enthusiasm engendered by these results and the severe nature of the problem resulted in the Lumbi Block initative previously mentioned. The principles, structure and results of this work are described in detail in the project report by J.Singh *et al.,* (1998c). The villages were, Mehna, Baghu, Kheowali, Singhe Wali, Fatuhi Wali, Maithri Budhgir, Gaggar, Mann, Bibowali, Channu and Badal. The PAU team provided the technical direction of the programme with three local staff recruited from each village and trained as 'IPM facilitators' stationed in each village. Each cluster of three villages was supported by a project Research Associate from PAU. Whole-village meetings were used to engender a sense of ownership of the demonstrations and farmers were allowed to self-select as to whether they would join the programme. Depending on uptake, some 20 farmers were allocated to each 'IPM facilitator', making around 600 initial 'participating' farmers in all. However, others were encouraged to join in as they wished and it is estimated that over 1000 farmers were following the programme in some major degree by the end of the season.

From the second week of June to the middle of October, pest and disease surveillance reports were sent weekly to the Punjab Director of Agriculture, Deputy Director for Cotton , Chief Agricultural Officers, the Cotton Corporation of India (Bathinda), District Extension Specialists (Plant Protection) and the Director of Research and the Director of Extension at PAU. This ensured a focus on the events in the block by the key decision makers.

Again the season was a very poor one for weather and pests across the Punjab limited the extent to which farmers were prepared to follow the recommended practices which, as is always the case in the first year, they perceived as carrying some risk. This was not helped by the patchy provision of support by the other project partners.

Table 5: Comparison of results from 42 farmers participating in the 1998-9 'best-bet' trials and those of 40 matched non-participating 'control' farmers. Costs in Rupees.

Parameters	IPM Farmers	Non-IPM farmers	Advantage to IPM Farmers
Numbers of farmers surveyed	42	40	
Operational land holding (total ha)	366	312	
Area under cotton (ha)	285	212	
Average number of sprays (per ha)	12.13	11.91	Increased 1.8%
% sprays given as mixtures	35%	72%	Reduced 51%
Average yield per ha	669 kg	448 kg	Increased 49%
Average insecticide cost /ha	5,168 Rs	6,554 Rs	Decreased 21%
Value of cotton/ha	14,719 Rs	9,848 Rs	Increased 49%
Cotton value – Insecticide cost	9,533 Rs	3,294 Rs	Increased 189%

Table 6: Costs and returns (rupees) for 42 farmers participating in the 1998-9 'best-bet' trials and those of 40 matched non-participating 'control' farmers.

	IPM farmers	Non-IPM farmers
Insecticide	5,168	6,554
Fertiliser	511	549
Seed	423	433
Machinery	1821	1774
Labour	2,908	2,779
Total cost	10,892	12,059
Gross return	14,719	9,848
Net return	3,827	-2,211

Clearly, cotton was not very profitable for either group in 1988-9. But equally, a modest profit was more welcome than a significant loss.

Environmental and human health benefits accruing from the reduced application of toxic ingredients are discussed below. It is perhaps worth noting that 96% of the health hazard was caused by the spraying of organophosphates and <1% by the pyrethroid spraying, reflecting the very low mammalian toxicity of pyrethroids (Iyengar and Russell submitted). For this reason alone, restoring failing efficacy of pyrethroids is worthwhile, pending the availability of more environmentally friendly and economically acceptable control methods.

Post-season meetings were held in each of the villages to ensue that the farmer concerns were addressed and the economics of the trials was fully understood.

Research papers, bulletins, handbook and newsletters available.
Reports, papers, bulletins, brochures, training manuals and newsletters have been produced covering a number of major topics. Full references are in the Publications Arising section. Some of the outputs (marked*) were joint productions with CPP project R6734 *'Development of an area wide strategy for the management of insecticide resistant cotton pests in southern India'* which also ran from 1996 to 1999, with the same NRI staff and a number of linked objectives.

<u>Descriptions of the irrigated cotton system and its problems in northern India</u>

*Elangovan and Overfield (submitted)	(journal article)
*Elangovan *et al.,* 1999	(project report)
Overfield and Malhan (submitted)	(journal article)
Bakhetia and Brar, 1998	(meeting paper)
Singh and Bakhetia, 1998	(meeting paper)
J.Singh *et al.,* 1998	(meeting paper)
Malhan, 1998	(project report)

<u>Insecticide use and control</u>

Bakhetia *et al*., 1998a	(meeting paper)
J.Singh *et al*., 1997	(project report)
J.Singh *et al.,* 1999	(project report)
J.Singh *et al.,* 1998a and b	(meeting papers)
*Cooper *et al.,* 1998	(training manual)
Singh and Cooper, 1998	(training manual)

<u>Insecticide resistance in *Helicoverpa armigera* and IRM strategies</u>

*Regupathy *et al.,* 1998	(international conference)
*Russell 1997, a and b	(meeting papers)
*Russell 1998, a and b	(meeting papers)
*Russell *et al.,* 1998	(international conference)
Kapoor, 1998	(meeting paper)
*Kranthi *et al.,* 1998	(meeting paper)
J.Singh *et al.,* 1998	(international conference)
J.Singh *et al.,* 1998	(meeting paper)

<u>Insecticide resistance in *Bemisia tabaci* and containment strategies</u>

D.Singh *et al.,* 1999	(journal article)
D.Singh, 1998	(meeting paper)
D.Singh *et al.,* 1998 a and b	(meeting papers)
Denholm, 1998	(meeting paper)

<u>Epidemiology and control of CLCuV</u>

J.Singh *et al.,* 1998	(international conference)

IRM Newsletters, farmer brochures and technical bulletins

*Podborer Newsletter 8 (1997), 9 (1998)	(newsletter)
*Kranthi and Russell, 1999	(IRM techniques manual)
*CICR 1998, 1999	(farmer IPM/IRM brochures)

IPM/IRM field implementation

J.Singh *et al.,* 1998c	(project report)

Other cotton pests

Sohi *et al.,* 1998	(journal article)

Impact on human health and beneficial insects of the developed IPM strategy

*Iyengar and Russell, 1999 (submitted)	(journal article)

IMPACT OF CONSTRAINTS:

Constraints foreseen in the project memorandum included the impact of poor weather and poor farmer motivation. In fact the 1997 cotton season had extremely heavy rainfall in September and especially October which resulted in disastrous flooding across much of the Indian Punjab cotton belt. This was in major part responsible for the 68% decline in cotton output per unit area in the Punjab when compared with the previous normal to poor year and completely destroyed the harvest in one of the two villages participating in the project in that year (Tarkanwalla, where much of the cotton was chest-deep in water). There was a very strong yield effect in other villages, including Gobindgarh and although participating farmers obtained 60% more yield than the matched non-participators, at 280 Kg seed cotton/ha, yields were still very low. The following season was very hot during planting necessitating significant re-planting. This hot, dry weather continued until September when unusually late and heavy rains again, particularly in October again caused fruit shedding and precipitated severe *H. armigera* attacks. Again yields were depressed, it being difficult to separate out the effects of weather from that of pests. It is increasingly clear that in years in which a dry summer is followed by a clear transition to heavy rains, *H.armigera* emergence is rapid and concentrated, resulting in pest pressure on the crop which is difficult to manage.

On the other hand, farmer motivation, mentioned as a possible constraint in the project memorandum, was not a problem in these years of exceptionally high pest pressure and very marginal economic benefit from cotton crop production.

The perceived risk that ICAR institutions would not invest in the uptake and application of research results has not come to pass. Control of *H. armigera* has moved to the top of the agricultural research agenda as losses from this species in India rose to exceed $500 million in 1998 despite some $300 million spent on control measures.

The impact of the lack of an enabling environment (policies, incentives, markets, institutions for widespread adoption of new technologies and strategies was more of a concern. With very high levels of farmer agitiation and clear appreciation of the importance of the cotton/wheat rotation in the economy of the Punjab (and indeed of India), political awareness of the problem of declining cotton yields and increasing cost of production, was certainly present. The Punjab government also showed very strong support with the creation of the Lumbi block 11 village initiative in 1998 which involved the Ministry of Agriculture extension services, the Cotton Corporation of India and MarkFed in addition to PAU and the state extension services. However, despite good co-ordination early in the season and signed agreements for the timely provision of inputs and support, translating decisions into action on the ground by the various agencies still proved very difficult. In particular the extension service staff, who it must be said, did not have the confidence of the villagers, were either unable (ordered vehicles did not arrive) or unwilling, to play a full and positive role. Likewise the promised timely availability of irrigation water did not materialise and even the quality of the cotton seed provision did not reach the expected standards, with many farmers having to replant significant areas with non-preferred varieties.

The Punjab has probably the best organised and certainly the most capital intensive agricultural sector of any state in India. That it should be so difficult for clearly expressed political will to translate into action on the ground in the relatively modest area of 11 villages must give pause for thought when extrapolating the possible benefits of this project to other areas in the Punjab and beyond. This confirms the project team's opinion that the priority at present is for simple measures to implement improvements in current practice, with the provision of appropriate germplasm, and a focus on reduction of inappropriate insecticide use. More complex recommendations requiring a major extension effort are currently unlikely to obtain the necessary support at farm level.

Environmental concerns:

It was foreseen in the project memorandum that major positive benefits to the environment will accrue from reduced reliance on, and more efficient use of, pesticides in cotton which currently accounts for over 50% of the 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.

In the small-scale work with farmers undertaken in 1997-8 it was possible to show a c.20% reduction in the number of insecticide applications used by participating farmers, despite the heavy pest pressure in that year. As reported above, the number of insecticide applications was not reduced amongst the much larger numbers of participating farmers in 1998-9 mainly due to the very high pest pressure across the whole region, with intervention thresholds for American bollworm exceeded for 107 days continuously from the fourth week of July to the first week of November during the cotton season of some 140 days. As indicated, poor collaboration from the extension services was a further concern. However, improvement in the environmental situation was obtained from use of a more appropriate insecticide quantity and the use of more effective materials with reduced environmental impacts on non-target organisms, and recommendations for the use of mixtures only when several pests susceptible to different chemicals were present and above threshold simultaneously. The quantity of active ingredient used was reduced by 29% and the human heath impact by 48% as measured by the reduction in the number of human LD_{50} doses of active insecticide ingredients applied in the field (Iyengar and Russell, in press).

Experience in other parts of India in the same seasons, under project R6734, indicate that in years of lower pest pressure, the reduction in quantity of active ingredient applied which can be achieved in village participatory trials averages 58% and the human health impacts were reduced between 76% and 93% (Iyengar and Russell in press). These sorts of results can be confidently expected in the Punjab if the momentum of this project can be maintained.

6 Contribution of outputs

The project has successfully identified and made widely known the factors at work within the Punjab which are contributing to the decline in cotton production (D.Singh 1998, D.Singh *et al.* 1998 a,b, 1999, J.Singh and Bakhetia, 1998, Overfield and Malhan in press) and has experimentally explored the directly pest-oriented problems in order to find ways of mitigating these production constraints. The project has produced a fuller understanding of the forces operating on the farmer; elucidated the epidemiology of the most devastating of cotton diseases, cotton leaf curl virus disease; formulated recommendations for insecticide use appropriate to cotton producers and has catalogued the insecticide resistance levels in the major pests. These have enabled the development of pest management decision recommendations which have been demonstrated in a cluster of 11 villages, to address the first project goal '*minimise the impact of significant pests of cotton'* by appropriate practices which greatly reduce the cost and environmental impact of control. This in turn has reduced the human health impact of pesticide use by at least 20%. It has addressed the second goal, to '*increase systems commodity production by optimising inputs and outputs*' to the extent of increasing yields by over 50% for participating farmers even in the two worst pest attack years on record and without increasing input costs.

Direct benefits already provided by the project include net return increases over non-participators averaging Rs 6,061/ha for the >1,000 participating farmers in a year of high pest pressure and atrocious weather. Low yields of only 694Kg seed cotton/ha were achieved by participating farmers, but this was 50% more than the non-participators who only achieved 464Kg/ha. Insecticide active ingredient was reduced by 29% (costs by 21%) mostly due to a 48% reduction in the number of applications of insecticide mixtures (Iyengar and Russell, submitted).

Much of this benefit comes from increased yields per unit area when compared with non-participating farmers (200% higher in 1997-8 and 50% higher in the heaviest pest pressure year of 1998-9). The benefits from the agronomic, as opposed to the interventional components of IPM cannot be disaggregated easily, but the number of farmers following the varietal recommendations was low in 1998 because of delays by the Punjab Government in selecting the project area. This suggests that most of the benefit in this year was from the change in insecticide use practices. Certainly the cost of producing 1 kg of seed cotton by participating farmers was 7.72Rs as opposed to 14.64Rs for farmers not in the programme. If comparable benefits could be secured over the c.2 million ha of cotton in the irrigated north zone of Rajastan, Haryana and the Punjab then some 200,000 farming families would directly and substantially benefit.

Target institute capacity support:
PAU has been provided with research facilities in the field of insecticide resistance management and with training in India and the UK to enable the effective utilisation of these facilities. The university now has a fully operating laboratory for the detection and routine monitoring of insecticide resistance in *H.armigera*, building on the existing laboratory of Dr Kapoor of the PAU Dept. of Entomology. The results of this monitoring from 1996-1999 are presented in the various issues of the *Podborer Newsletter* and the publications arising. These results have underpinned the recommendations for insecticide use in the Northern Zone (Bakhetia *et al.* 1998, Singh *et al.* 1998a). In addition the Entomology Department now has an equipped and functioning whitefly insecticide resistance laboratory. Dr Darshan Singh, head of the laboratory, and his assistant Ms Nandita Sharma were trained at Rothamsted and NRI in the techniques of whitefly rearing, insecticide resistance measurement and in the use of the Polo probit analysis package. In addition the CLCuV research capacity was strengthened, laboratory and screenhouse work on the epidemiology of the disease undertaken and a much fuller picture of the role of weeds as alternate host of the disease was obtained. Resistant germplasm was identified and appropriate pesticide recommendations made for the control of *B. tabaci* within the total pest complex.

Follow-up indicated and planned

Northern states
At the end of the 1998-99 season an important meeting *'Critical issues of IPM in the changing agricultural scenario of India'* was held at PAU, Ludhiana at which all these matters were aired to the main MOA/ ICAR and agricultural university decision makers. The recommendations of this meeting were endorsed by the Directors of Agriculture for the three Northern States at a meeting on 12 January 1999, as the action plan for the 1999 season. This plan recommended the multiplication and planting of the recommended varieties as above; the treating of seed with imidocloprid against jassid pests; the application of insecticides on the basis of established economic thresholds; the banning of synthetic pyrethroids for bollworm control and the recommendation that only chlorpyrifos, quinalphos, triazophos and profenofos be used for *H. armigera* control. The supply of better quality insecticides is to be improved and the adoption of more efficient boom sprayers promoted. A programme to uproot the weed hosts of CLCuV was also announced. Further support for the development of appropriate short-stature, short-season, pest and disease resistant cotton cultivars was also decided. These decisions vindicate the project's concentration on developing and demonstrating these recommendations.

These recommendations for the northern districts differ in a number of important ways from those for more central and southern districts, where the pest complex is different in the timing and sequence of attack and the cotton varieties, agronomy and insecticide resistance scenario are different. Nevertheless the principles of, for example, minimising applications of toxic materials early in the season by the use of sucking pest tolerant varieties or insecticidal seed treatment are of uniform applicability. Many of these principles were developed under the preceding project (R5745CB) and built on here and in the concurrent project in southern India (R6734). At a national level the IPM programme has thus been presented as comprising local modifications on a general theme. Much of the uptake described below therefore refers to national, rather than purely Punjabi initiatives.

ICAR national 'village adoption' project :
The technical and farm-level success of the project in providing explanations and solutions for the desperate problem of the management of insecticide resistant pests has resulted in a number of initiatives picking up this adaptive research. The Indian Council for Agricultural Research has begun funding a four year programme of 'village adoption' by ICAR institutes to implement the developed package of practices in the states in which the projects worked (including R6734 project states). The northern site is at Sirsa, close to the regional station of the Central Institute for Cotton Research (CICR) with training provided by PAU and the CICR Nagpur team. It is hoped that this will act as a model for expansion of these ideas into other areas, although the capacity of the CICR Sirsa staff to successfully implement a participatory extension programme (rather than researcher-managed trials) has yet to be demonstrated at this station.

National Agricultural Technology Project:
Through the World Bank National Agricultural Technology Project (NATP), approval has been obtained for the funding of a network of insecticide resistance laboratories in nine states, including support for the previously DFID-supported laboratories in the Punjab, Maharashtra and Tamil Nadu. The leading laboratory for this project on *H. armigera* study is at Dharwad in Karnataka but the resistance component is to be led from the project laboratory at Nagpur which is clearly now the leading national centre. The ICRISAT laboratory, although theoretically eligible for this funding has been excluded from the work and has ceased to function following the end of the current project. This support should enable the national laboratories to continue monitoring changes in the resistance pattern and recommending concomitant changes in pesticide use practice. Despite approval having been given from April 1998, this, along with most other approved NATP projects, had not started by April 1999. The reasons are not clear, although a further review or additional project clearance steps appear to be in the offing. This delayed start is unfortunate as the laboratories are having great difficulty retaining trained staff and resources pending its commencement.

Cotton Corporation of India IPM initiative:
The Cotton Corporation of India (a parastatal which intervenes in the cotton market to support farmer minimum prices) has very substantial funds for the support of IPM programmes. These have been used to support the provision of inputs of quality seed, pheromone traps and pesticide into some 200 villages in each of the last few seasons. However it became apparent that the current long-term impact of this funding is minimal as an understanding of the principles of sustainable pest management are not being inculcated when the inputs are provided (a single half-day seminar for growers normally comprises the training component). Efforts are being made, in discussions with CCI IPM programme leader, Dr Basu (ex Director of CCRI Nagpur) to re-orient this programme towards the provision of support for the training and support of local IPM agents to implement the programme outlined above. At a meeting in Ludhiana in April 1999 CCI agreed to provide support of this type in eight villages in three cotton districts of the Punjab in 1999. Finance for village level IPM facilitators, mobility and the provision of good quality pesticides at cost will be provided by CCI, with supervision provided by the PAU project team. Discussions are underway to expand this model to other states.

Central Institute for Cotton Research National Initative:
In order to further capitalise on the momentum generated by the project work, the Central Institute for Cotton Research at Nagpur has launched an ambitious plan to take the IRM practices to 5 villages in each of the 25 districts using insecticides most heavily, covering eight of the cotton producing states (Punjab, Maharashtra, Myda Pradesh, Haryana, Rajistan, Andhra Pradesh, Tamil Nadu and Karnataka). This plan involves the active co-operation of a number of agencies including the chemical and fertiliser companies, the agricultural universities in the states concerned, para-statals such as KRIBCO, IFFCO and the Cotton Corporation of India and the ICAR research institutions. The Union Commissioner for Agriculture has obtained approval for the funding of this work and the equivalent of £450,000 has been allocated over the three years from 1999-2000. This requires only approval from the Indian cabinet. Training sessions early in the cotton season were organised for the participating organisations in the north (CICR Sirsa), Centre (CICR Nagpur) and south (Madras). Participation of the self-funded organisations seems to be progressing quite well. For example Excel Industries, major manufacturers of endosulfan have participated in the plan to the extent of setting up demonstration fields in over one hundred villages across India and appointing staff to manage and implement the demonstrations in clusters of villages. This uptake is probably typical of the type of enthusiastic but partial support which self-funding organisations are offering. Excel wishes to place its products within the programme and finds it easier to get marketing department approval if the number of demonstrations is multiplied at the expense of the area-wide and participatory benefits. A number of government organisations have indicated willingness to participate. Unfortunately the change of government in the early summer of 1999 has delayed cabinet approval of the funding. This has been a major brake on the expansion of the programme. Dr Hazra, the Union Commissioner for Agriculture is confident of the funding but its late appearance may emasculate the programme in future seasons in many areas.

Impact promotion support:
A number of issues arise. The scale and diversity of the NARS system in India makes maintaining the direction of developed IPM systems in the national follow-on programmes described above, difficult. Even in the absence of direct inter-organisational rivalry there is frequently a reluctance to be a follower rather than a leader and CICR's forceful leadership style is sometimes counter-productive. Some form of facilitation and co-ordination of the inputs of these diverse organisations is desirable. This point is conceded by the Assistant Director General for Plant Protection at ICAR , the officer in charge of the NATP at ICAR, the Union Agriculture Commissioner, and industrial participants. Support has been sought from DFID for such co-ordination. Given the success of the sister project R7634 in obtaining even more striking benefits in three more southerly Indian states over the same period, and the potential benefit to the country's 17 million cotton workers, consideration of support for this by the UK bilateral programme would seem appropriate. Dr M Wilson, at that time DFID Natural Resources Advisor in New Delhi, was supportive in principle but had problems funding such work at relatively short notice.

In the event promotion support has been provided for June 1999 to March 2000 by the CPP (project no ZA0341). This covers biological and socio-economic input from the UK into the regional IRM training workshops in North, Central and South India for the National IRM Initiative under the Cotton Technology Mission programme mentioned above, and follow-on technical support as required. Provided the programme funds are released in a timely fashion by the Indian Government ,this has the potential to make a major impact on pesticide use in India's cotton.

Future donor-funded technical work in the region:
With the backing of the International Cotton Advisory Committee, the work of expanding and improving the science base for resistance management is continuing through a large ($ U.S.4.8 mill) Common Fund for Commodities (CFC) funded project *'Sustainable control of the cotton bollworm* Helicoverpa armigera *in small-scale cotton production ' (2000 – 2004).* This joint project between India, China, Pakistan and the UK, led from NRI aims to fill the remaining gaps in our technical knowledge of sustainable, mixed control strategies for *H.armigera* and has the following components:

- Reviewing the impact of insecticides on beneficial insects;
- Monitoring the changes in insecticide resistance across the region *(state funded);*
- Clarifying the relationships between laboratory measured levels of resistance and subsequent field control;
- Identifying the principles underlying insecticide mixtures which are effective but not enhance resistance;
- Producing cheap insecticide quality and resistance detection kits;
- Identifying the minimum specifications for effective insecticide application;
- Condensing all the existing information on sustainable control of *H.armigera* into a handbook of management and disseminating the information through a series of national and regional workshops in Asia and Africa;

The Punjab Agricultural University will be leading on the insecticide application component and has an important role to play in other components. Permission has been sought to retain the technical equipment provided by the current project for the measurement and determination of insecticide resistance in cotton pests and the project vehicle to maintain the mobility of the research team for the field components.

The CFC is to provide $2 million, the governments of the three cotton producing countries are providing $373,000 including $174,000 from ICAR and the collaborating laboratories are providing $1,1mill in kind. ($275,000 in India). The CFC wishes to see the UK technical input (as opposed to project technical and financial management costs) funded from within the UK. Support is being sought from the Crop Protection Programme.

In addition the EU is funding a project *'Integrated pest management in cotton in Asia'* aimed at utilisation of the farmer field school (FFS) methodologies for the promotion of sustainable pest management in cotton in Asia. This five year, ECU 12 million project covers India, Pakistan, China, Bangladesh, Vietnam and the Philippines. Some 90,000 farmers are expected to be trained over the project life from Oct 1999 to Sept 2004. The current project staff at PAU will lead the N.India component. Dr Russell attended the inaugural workshop and has been involved in the provision of curriculum advice on the role of insecticides in cotton IPM. Key documents have been provided, based on the outputs of this project. The programme will draw significantly on the research results of the current project in promoting cotton IPM in the region.

7 Publications

*Those marked * were written with R6734 ' Development of an area-wide strategy for the management of insecticide resistant cotton pests in southern India' which also ran from 1996 to 1999 and shared the same project UK staff and many of the objectives, though for dry-land cotton.*

Journal Articles

* ELANGOVEN, P., OVERFIELD, D., ALI, M.A., MALHAN, R.S. (1999) Constraints to the adoption of sustainable pest control practices in cotton in India**.**

* ELANGOVAN, P and OVERFIELD,D. (submitted 1999). Dimensions of adoption and sustainability in the use of insecticide resistance management techniques in different parts of India. *Agricultural Systems*.

* 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*.

* OVERFIELD, D. and MALHAN, R.S. (submitted 1999). The Green Revolution; changing farming systems and declining cotton yields in the Indian Punjab. *Journal of Development Studies*.

SINGH, D., DENHOLM, I., RUSSELL, D.A., SINGH, G., SOHI, B.S., SARAO, P.S. and SHARMA, N. (submitted 1999). Monitoring of insecticide resistance and esterase variations in cotton whitefly *Bemisia tabaci* (*Gennadius*) from the Indian Punjab.

SOHI, A.S., MANN, H.S., SINGH, JOGINDER, BRAER, D.S., SARAO, P.S., KUMAR, V. and DHILLON, H.S. (1998) Influence of insecticidal sprays on the reproduction of *Aphis gossypii* Glover on *hirsutum* cotton. *Insect Environment* **4**(2):51.

Conference Presentations

* REGUPATHY, A., JADHAV,D., KAPOOR, S.K., SINGH, D., KRANTHI, K. and Russell, D. (1998) (In Press). Patterns of insecticide resistance in India in *Helicoverpa armigera* and *Bemisia tabaci*. World Cotton Research Conference II, Athens 6-12 September, 1998.

* RUSSELL, D.A. (1997)a Insecticide resistance and its management in *Helicoverpa armigera* (*Lepidoptera: Noctuidae*) in India. Silver Jubilee Meeting of the Plant Protection Association of India, Hyderabad, 20-24 December 1997.

RUSSELL, D.A. (1997)b Insecticide resistance and its management in *Helicoverpa armigera* (*Lepidoptera: Noctuidae*) in India. Invited keynote paper of the National Seminar on Insecticide Resistance in *Helicoverpa* and Pesticide Application Technology. Insecticide Resistance Action Committee, India. Secunderabad, 20 December 1997.

* RUSSELL, D.A. (1998)a Monitoring, mechanisms and management of insecticide resistance in *Helicoverpa armigera* (*Lepidoptera: Noctuidae*) in India. In: B.M.Vithal (ed.) *Proceedings of the National Seminar on strategies for the improvement of production, productivity and quality of cotton*. Cotton Corporation of India and Indian Cotton Development Corporation, Bombay, 4-5 May 1998.

*RUSSELL,D.A., SINGH, J., JADHAV, D.J., SURULIVELU, T., REGUPATHY, A. and KRANTHI, K. (1998)(In Press). Management of insecticide resistant *Helicoverpa armigera* in cotton in India. World Cotton Research Conference II, Athens 6-12 September, 1998.

*RUSSELL, D.A., KRANTHI, K.R. and JADHAV, D.R. (1999). Sustainable cotton pest management in India. Proceedings: *International Seminar on cotton and its utilisation in the 21st Century*. [abstract pp399-340], CIRCOT, Mumbai. December 10-12, 1999.

SINGH, J., SOHI, A.S., BRAR, D.A., DENHOLM, I. and RUSSELL, D.A. (1998) (In Press). Management of cotton leaf curl virus in India. World Cotton Research Conference II, Athens 6-12 September, 1998.

Meeting Papers

BAKHETIA, D.R.C., SINGH, J., JOIA, B.S. and SOHI, A.S. (Jr)(1998)a. Quality control of insecticides under the Insecticides Act, 1968 – A case for amendments. *Proceedings of the National Seminar on 'Critical Issues of IPM in the changing agricultural scenario of India'*. Punjab Agricultural University, Ludhiana, November 28-29, 1998.

BAKHETIA, D.R.C. and BRAR, D.S. (1998) Critical issues of biological control in IPM. *Proceedings of the National Seminar on 'Critical Issues of IPM in the changing agricultural scenario of India'*. Punjab Agricultural University, Ludhiana, November 28-29, 1998.

DENHOLM, I. (1998) Challenges with combating insecticide resistance in cotton pests in India. *Proceedings of the National Seminar on 'Critical Issues of IPM in the changing agricultural scenario of India'*. Punjab Agricultural University, Ludhiana, November 28-29, 1998.

KAPOOR, S.K. (1998) *Helicoverpa armigera* resistance in the Punjab. Final meeting of the *Heliothis* Network Research Project (ICAR), PAU Ludhiana, June 24-25, 1998.

*KRANTHI, K.R., JADHAV, D.R., WANJARI, R.R. and RUSSELL, D.A. (1998) IRM strategies for sustainable cotton pest management in India. *Proceedings of the National Seminar on 'Critical Issues of IPM in the changing agricultural scenario of India'*. Punjab Agricultural University, Ludhiana, November 28-29, 1998.

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

SINGH, D. (1998) Resistance in *Bemisia tabaci* in the Punjab. *Proceedings of the final meeting of the Heliothis Network Research Project* (ICAR), PAU Ludhiana, June 24-25, 1998.

SINGH, D., SINGH, G., DENHOLM, I., RUSSELL, D.A., SOHAL, B.S. and SARO, P.S. (1998)a Population structure of *Bemisia tabaci* (*Gennadious*) in the Punjab and its implications in insecticide resistance management. *Proceedings of the National Seminar on 'Critical Issues of IPM in the changing agricultural scenario of India'*. Punjab Agricultural University, Ludhiana, November 28-29 1998.

SINGH, D., DENHOLM, I., RUSSELL, D.A., SHARMA, N. and SARO, P.S. (1998)b Insecticide resistance patterns in whitefly, *Bemisia tabaci* (*Gennadious*) from the Punjab. *Proceedings of the National Seminar on 'Critical Issues of IPM in the changing agricultural scenario of India'*. Punjab Agricultural University, Ludhiana, November 28-29 1998.

* SINGH, J. Field management of insecticide resistance in the Punjab. (1998) *Final meeting of the Heliothis Network Research Project* (ICAR), PAU Ludhiana, June 24-25, 1998.

SINGH, J. and BAKHETIA, D.R.C. (1998) Critical issues of IPM in the changing agricultural scenario in the Punjab. *Proceedings of the National Seminar 'Critical Issues of IPM in the changing agricultural scenario of India'*. Punjab Agricultural University. Ludhiana, November 28-29 1998.

SINGH, J., BAKHETIA, D.R.C.., SOHI, A.S.(Jr), JOLA,B.S. (1998)a Synthetic pyrethroids and pesticidal combination products in agriculture – retrospect and prospects. *Proceedings of the National Seminar on 'Critical Issues of IPM in the changing agricultural scenario of India'*. PAU, Ludhiana, Nov 28-29 (1998). Summarised from a paper presented at the 'Technical review on the use of synthetic pyrethroids and pesticide combination products' convened by the Plant Protection Advisor to the Govt of India, April 5 1998, FICCI Auditorium, New Delhi.

SINGH, J., SINGH, D., SOHI, A.S., BRAR, D.S., KAPOOR, S.K., and RUSSELL,D.A. (1998)b Role of chemistry in the management of insect pests of cotton North India – and analysis. *Proceedings of the National Seminar on 'Critical Issues of IPM in the changing agricultural scenario of India'*. PAU, Ludhiana, November 28-29 1998.

SINGH, J., SOHI, A.S., BRAR, D.S., BAKHETIA, D. and RUSSELL, D.A. (1998) Management of the 'In Crisis' cotton crop in north India. . *Proceedings of the National Seminar on 'Critical Issues of IPM in the changing agricultural scenario of India'*. PAU, Ludhiana, November 28-29 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

* 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.

SINGH, J. and COOPER,J. (1998) PAU/NRI course on cotton pest management and spray application in the Punjab, India. Pp 32. PAU, Ludhiana. August 20, 1998.

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

* CICR (1998). Insect Pest Control. Colour brochure in local languages detailing cotton pests and their management – farmer handbook of project practices for each ear. Two editions. August (1998) 2,000 copies (sold out) and Dec (1998), 2,000, 3rd edn. in press. CICR, Nagpur

Project Reports

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

MALHAN, R.S. AND SINGH J. (1998). A systems approach to sustainable insect pest management in irrigated cotton in India. Part I – Overview of the cotton industry.pp23. Part II – Summary of the impact of IPM 5pp.

SINGH, J., BAKHETIA, D.R.C., SOHI, A.S.(Jr), BRAR, D.S. (1998)c Progress report: Cotton IPM in eleven villages of Lumbi block of district Muktsar, Punjab during the Kharif (1998) crop season. (pp 42).

SINGH, J., SOHI, A.S.(Jr), COOPER, J. and BRAR, D.S. (1997) Field evaluation of three different sprayers on American cotton in the Punjab, India during the (1997) season (6pp).

SINGH, J., SOHI, A.S.(Jr), COOPER, J. and BRAR, D.S. (1999). Evaluation of two different sprayers on hirsutum cotton in the Punjab, India during the (1998)-99 season (3pp)

8 References

ANON (1991) *Heliothis* management. Current status and future strategies. Recommendations of the first national workshop. Directorate of Pulses Research, Kanpur, India. 30-31 August 1990.

ARMES, N.J., BANERJEE, S.K., DESOUZA, K.R., KING, A.B.S., KRANTHI, K.R., REGUPATHY, A., SURULIVELU, T. and VENUGOPAL RAO, N. (1994) Insecticide resistance in *Helicoverpa armigera* in India: recent developments. *Proceedings Brighton Crop Protection Conference - Pests and Diseases.* 1994. Pp. 437-442.

ARMES, N.J., JADHAV, D.R. and LONERGAN, P.A. (1995) Insecticide resistance in *Helicoverpa armigera* (Hübner): status and prospects for its management in India. Proceedings World Cotton Research Conference -1, Brisbane, Australia, 13-17 February 1994. Pp. 522-533.

ARMES, N.J., JADHAV, D.R. & K.R. DESOUZA (1996) (In press).
A survey of insecticide resistance in *Helicoverpa armigera* in the Indian subcontinent. *Bulletin of Entomology Research.*

BAKER,D.N., HESKETH, J.D., DUNCAN, W. (1972). Simulation of growth and yield in cotton. *Crop Science* **11**:431-435.

BROOK, K., HEARN, A. (1983). Development and implementation of SIRATAC: a computer based cotton management system. Proceedings of the First National Conference Comp. Agriculture. University of Western Australia, Perth pp 222-240.

CAHILL, M., JOHNSTON, D., GORMAN, K. and DENHOLM, I. (1994) Insecticide resistance in *Bemisia tabaci* from Pakistan. Procreedings of the Brighton Crop Protection Conference. - Pests and Diseases 1994.

DHINGRA, S., PHOKELA, A., & MEHROTRA, K.N. (1988) Cypermethrin resistance in the populations of *Heliothis armigera* Hubner. National Academic Science Letters, Vol II, pp123-5.

GILLHAM, F.E.M., BELL, T.M., ARIN, T., MATTHEWS, G.A., LERUMEUR, C., HEARN, A.B. (1995). Cotton production prospects for the next decade. World Bank Technical Paper No. 267, The World Bank, Washington D.C., USA.

GUTIERREZ, A. FALCON, L., LOEW, W., LEIPZIG, P. and VAN DEN BOSCH R. (1975). An analysis of cotton production in California; a model for Acala cotton and the effects of defoliators on its yield. *Environmental Entomology*, **4**, pp125-126.

GUTIERREZ, A., BUTLER, G., WANG,Y., WESTPHAL, D. (1977). The interaction of pink bollworm (*Lepidoptera: Gelichiidae*) cotton and weather: a detailed model. *Canadian entomologist* **109**, pp1457-68.

GUTIERREZ, A., DAXL, R., QUANT, G. and FALCON, L. (1981). Estimating economic thresholds for bollworm *Heliothis zea Boddie* and boll weevil *Anthonomus grandis Boh*., damage in Nicaraguan cotton, *Gossypium hirsutum L. Environmental Entomology* **10**, pp 872-879.

GUTIERREZ, A., DE VAY, J., PULLMAN, G. and FRIEBERTHAUSER, G. (1983). A model of verticillium wilt in relation to cotton growth and development. *Phytopathology* **75**, pp 89-95.

GUTIERREZ, A., PIZZAMIGLIO, M., DOS SANTOS, W., TENNYSON, R. and VILLACORTA, A. (1984). A general distributed time-varying life table plant population model: cotton (*Gossypium hirsutum L.*) growth and development as an example. *Ecological Modelling* **26**, pp 236-249.

HOLT, J., NORTON, G.A. (1993) Simulation models in decision tools for pest management. CABI: Wallingford. pp 119-146.

HOLT, J., WAREING, D.R. and NORTON, G.A. (1992) Strategies of insecticide use to avoid resurgence of *Nilaparvata lugens* (Homoptera: Delphacidae) in tropical rice: a simulation analysis. *Journal of Economic Entomology*, **85**, pp1979-1989.

KRANTHI, K.R., ARMES, N.J., RAO, N.V., RAJ S. and V. T. SUNDARAMURTHY. (In Press) Seasonal dynamics of metabolic mechanisms mediating pyrethroid resistance in Helicoverpa armigera in central India. *Pesticide Science*.

LYON, D.J. (1996) Cotton pest management research - review and prioritisation. Renewable Natural Resources Research Strategy 1995-2005. NRI unpublished report.

MALHAN, R.S. (1998). A systems approach to sustainable insect pest management in irrigated cotton in India. Part I – Overview of the cotton industry.pp23. Part II – Summary of the impact of IPM, 5pp.

MANETSCH, T. (1976) Time varying distributed delays and their use in aggregate models of large systems. *IEEE Transactions System Management Cyber*. **6**, pp 547-553.

MEHROTRA, K.N. (1990). Pyrethroid resistant insect pest management: Indian experience. *Pesticide Research Journal,* **2**, 44-52.

NORTON, G.A. and MUMFORD, J.D. (1993). Decision tools for pest management. CABI: Wallingford. pp279.

RUSSELL, D.A., RADWAN, S.M. (1992): Modelling the impact of cotton fruiting phenology on pink bollworm population dynamics in Egypt. In: S.Mejen, J.Visser and P.Harrewijin (eds.) *Proceedings of the 8th International Symposium on Insect Plant Relationships,* Wageningen, Netherlands, 9-13 March 1992, pp 323-324. Kluwer Academic Publ., Dordecht, Netherlands.

RUSSELL, D.A., EL-HAMAKY, M., MOAWAD, G., RADWAN S., EL-DEIB, Y. (1994) Present use and future prospects for the COT cotton plant, pest and management model in Egypt. *Proceedings Egyptian Crop Health Conference 1994: Future of IPM in crop health and sustainable agriculture*. Fayoum, Egypt 21-24 March, 1994.

RUSSELL, D.A., ABO-GHALI, E., ABO-GHALI M. (1995). The use of the MOA/NRI cotton model for pink bollworm control in Fayoum and Beni Suef - 1995 season. Unpublished report to the Egyptian MOALR, American University in Cairo, pp38.

SINGH, J., SOHI, A.S., MANN, H.S. & KAPUR, S.P. (1994) Studies on whitefly, *Bemisia tabaci* (*Genn*.) transmitted cotton leaf curl disease in Punjab. *Journal of Insect Science*. **7**: pp194-98.

STERLING, W., DEAN, D., HARTSTACK, A. SHAHED, A and BURUDUGUNTE, R. (1993). TEXCIM for Windows: the Texas cotton- insect model. Texas Agriculture Experiment Station. Miscellaneous Publication, MP - 1646 (revised).

STONE, N., GUTIERREZ, A.(1986) Pink bollworm control in southwestern desert cotton. Hilgardia **54**(9), 1-56.

SUNDARAMUTHY, V.T., JAYASWAL, A.P., BHAMBURKER, M.W. and BANEJEE, S.K. (1990) Insect pests and their management in cotton. Pp. 88-95, in, BASU, A.K., MANNIKAR, N.D. and NARAYANAN (eds.) Cotton scenario in India. Indian Council of Agricultural Research, Pusa, New Delhi 110 012, India.

VON ARX, R., BAUMGAERTNER, J. And DELUCCHI, V. (1983) A model to simulate the population dynamics of *Bemisia tabacci Genn* (*Stern., Alyrodidae*) on cotton in the Sudan Gezira. *Zeitschrift Angew. Entomologie* **96**, pp341-363.

WEST, A. J. & MCCAFFERY, A.R. (1992). Evidence for nerve insensitivity to cypermethrin from Indian strains of *Helicoverpa armigera*. Proceedings of Brighton Crop Protection Conference, 1992. pp. 233-8.