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Review Article

Understanding natural enemies; a review of training and information in the practical use of biological control

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Abstract

The limitations of conventional methods of training and information provision on natural enemies are discussed. Farmer and popular understanding and perceptions about natural enemies are described. Lessons drawn and limitations encountered in traditional research and extension 'top-down' educational activities are examined and some of the more promising approaches are described. The constraints posed by the dearth of good quality information literature are discussed, together with best ways of making use of the information available. Specific problems arising from the lack of understanding of microbial control agents' modes of action are outlined. Some innovative programmes using discovery-learning methods with farmers to make better use of biological control (the Farmer Field School (FFS) approach) are detailed, with case studies from vegetables in the Philippines, cotton in Pakistan, coffee and vegetables in Kenya and rice in Indonesia. The importance of these new approaches in influencing policy-makers is assessed.

Introduction

One of the first documented examples of farmer awareness of natural enemies is the manipulation of predatory ants by Chinese citrus growers, dating back to ancient times. These farmers placed nests of *Oecophylla smaragdina* F. (Hym., Formicidae) in mandarin orange trees to help control leaf-feeding insect pests and used bamboo bridges to help the ants cross between trees (McCook 1882, in DeBach, 1964). Several centuries have passed since then and an understanding of natural enemies is generally confined in countries of both the North and South to a select handful of entomologists, integrated pest management (IPM) practitioners, amateur naturalists and a few gardeners and farmers.

Disenchantment with dependence on synthetic pesticides for pest control is growing worldwide, partly through concerns about the direct and indirect human health and environmental risks associated with their use, but also due to the failure of chemical control strategies to solve certain pest problems effectively or economically. Conservation of natural enemies is surely the cornerstone of an IPM approach, yet methods for assessing the impact of natural enemies and for encouraging their activity in cropping systems have been poorly studied by researchers, compared with the interventionist strategies of augmentation and classical biocontrol (Waage, 1996). If those already familiar with the concept of biocontrol fail to appreciate the significance of native natural enemies in keeping pests in check, it is hardly surprising that cropping systems which make full use of the potential of biological control agents for pest management are so few, particularly in tropical regions. Pest resurgence, due to elimination of natural enemies through excessive pesticide usage and the development of pesticide resistance in the target pests, is a frequent phenomenon in several cropping systems, notably cotton, rice, vegetables and fruit crops (e.g. Lim, 1992). Farmers, extension staff and policy-makers are only now coming to understand the causes of this resurgence phenomenon.

The challenge for the biocontrol research and extension community therefore is to enable small and medium scale farmers to access and use the wealth of biocontrol knowledge accumulated and to make this work for them. Failure to look at pest management problems and solutions from the point of view of smallholders, compounded by poor linkages between research, extension and farmers, is one of the reasons for the limited adoption of IPM, including biological control technologies, as many authors have analysed, e.g. NRI (1995).

This paper reviews conventional training and information provision on natural enemies and describes some innovative programmes in working with farmers to make better use of biological control.

Popular Perceptions of Natural Enemies and Biocontrol

A few large, easily observed arthropod predators, notably spiders and ladybirds, are well known to many people, although their lifestages and impact on insect pests and other prey are poorly understood. Few lay people, for instance, recognize the larval stages of ladybirds and even fewer are aware of the vast array of parasitoids and insect pathogens which exist in most agroecosystems. As Bentley has pointed out in an illuminating study of the differences between farmers' and scientists' knowledge of insects (Bentley, 1992), farmers may classify in great detail insects which are both easily observable and culturally important, forming part of rural life. He describes how Honduran smallholders are able to distinguish, for example, a range of bees and social wasps by their flight patterns, a skill well beyond the scope of many entomologists. However, the same farmers are not aware of the existence of parasitic wasps and their perceptions of vespid hunting wasps are confined to stinging and nest building – the work patterns of rural people and their direct experience of the more annoying aspects of wasp behaviour are unlikely to lead them to a detailed knowledge of the carnivorous nature of wasp larvae.

As a consequence of the general lack of awareness of the role of natural enemies, few cases of their encouragement in farming or garden systems are recorded, compared to the growing literature on farmer-generated pest control methods using plant-based or other organic material (e.g. Stoll, 1992 or Hunter, 1996). Most of those cases which do exist involve larger and more obvious predators; for instance, cereal and pulse farmers in India may erect wooden bird perches in their fields to provide sites for insect-eating birds to prey on caterpillar pests in the crop. Another widespread tactic is the use of domestic livestock such as ducks or chickens to forage on troublesome pests; for instance smallholders in Western Kenya insert bundles of fresh grass into termite mounds to attract termites. When the bundles are crawling with termites, the farmers pull them out and feed the termites to poultry (Adoyo *et al*., 1997).

Unfortunately, popular perceptions of biocontrol tend to dwell on spectacular failures rather than the successes, particularly of classical biocontrol. Such gross errors as the cane toad in Australia, a notorious case of the misjudged introduction of a generalist predator for control of beetle pests in sugarcane, I trust, are a thing of the past. However, the criticism of biocontrol has continued among certain environmental and development circles in North and South, with current controversy over host specificity in the field of herbivorous beetle agents introduced against thistles in North America (Anon., 1997) and against *Parthenium* weed in India (Evans, 1997). Scientists working in sustainable agriculture and biodiversity-focussed NGOs (non-governmental organizations) in India recently expressed strong views on the 'unnaturalness' of biocontrol and its inappropriateness to solve pest, weed and disease problems of smallholders (G.S. Reddy & V. Ramprasad, pers. comm.). High profile media stories which incorrectly reported that the *Parthenium*-specific weevil was attacking sunflower (in fact, the weevil has only been found feeding on *Parthenium* pollen blown onto this crop) may explain these negative reactions (Jayanth *et al*., 1993).

As biocontrol practitioners we, therefore, have a double responsibility to promote a wider understanding of natural enemies amongst the general public, as well as our more immediate farming and extension colleagues. The following sections discuss lessons and limitations encountered in traditional research and extension educational activities and go on to describe some more promising approaches.

Lessons for IPM Training from Classical Biological Control

Many introduction programmes of biocontrol agents for exotic pests have bypassed any direct farmer involvement at the implementation stage. As Andrews *et al.* (1992) point out, taking farmers out of the technology transfer equation in these programmes may be a positive advantage in the eyes of scientists, since it avoids many risks and complications while farmers receive the benefit. Certainly the introduction of the parasitoid *Epidinocarsis lopezi* (De Santis) (Hym., Encyrtidae), distributed by aeroplane drops across thousands of square kilometres in Africa, for control of the cassava mealybug *Phenacoccus manihoti* Matile-Ferrero (Hom., Pseudococcidae) was a universally acclaimed success carried out by international and national research bodies with minimal participation of cassava growers. On the other hand, both the cassava case and the contemporary introduction of two parasitoids for control of the mango mealybug *Rastrococcus invadens* Williams (Hom., Pseudococcidae) in Central and West Africa provide clear examples of the need for close collaboration between research organizations, governments, extension services and donors for such a project to be successful (Neuenschwander, 1993). The same author also notes that the damage to ornamentals by the mango mealybug in their own urban gardens spurred local decision-makers into action in support of an introduction programme.

Although excluding farmers from the process may not alter the effectiveness of programmes such as those described above, lack of farmer involvement and understanding of biological control may severely reduce the impact of introduced control agents in many cropping systems. In parts of Southeast Asia where the parasitoid *Diadegma semiclausum* Hellen (Hym., Ichneumonidae) was introduced some years ago for control of diamondback moth *Plutella xylostella* (L.) (Lep., Plutellidae) in brassicas, it has failed to have much effect in release areas where farmers are spraying heavily with broad spectrum insecticides and thus eliminating both introduced and native natural enemies.(Waage, 1996; Gyawali, 1997). Evidence from Malaysia suggests that sublethal effects on parasitoid fecundity and lifespan of even selective pesticides, such as insect growth regulators, may have a significant effect on the success of biocontrol introduction programmes (Furlong & Wright, 1993). I shall return to the *Diadegma* example below to illustrate the power of extension approaches centred on farmer awareness-raising about natural enemies to bring about substantial changes in farming practice and policy.

Actively promoting farmer participation and public education is being seen increasingly as a prerequisite for success of classical biocontrol programmes. This applies particularly to situations where current pesticide use needs to be carefully integrated with the release of control agents or where establishment and control is a long-term process. In the Caribbean, for example, the classical biocontrol programme against the hibiscus mealybug *Maconellicoccus hirsutus* (Green) (Hom., Pseudococcidae), which arrived in Grenada in 1993-94 and rapidly spread to neighbouring islands, has included a public education campaign in the media about the pest and its introduced natural enemies, the encyrtid wasp *Anagyrus kamali* Moursi (Hym., Encyrtidae) and the coccinellid mealybug predator *Cryptolaemus montrouzieri* Mulsant (Col., Coccinellidae) (IIBC, 1997). The mealybug attacks a very wide range of commercial and garden fruit, timber trees, vegetables and ornamentals, hence the programme aims to raise awareness among farmers and the public about the dangers of reliance on chemical control, emphasizing the IPM options for pest control.

In Australia, the lack of effective extension systems for release and redistribution of biological control agents has been recognized as the weak link in many weed biocontrol programmes (Briese & McLaren, 1997). However, since the mid-1990s local community groups allied to the Landcare movement have played an increasingly active part in release networks for weed control agents (arthropods and fungal pathogens) for over a dozen exotic invasive species. These authors describe the role of community networks as a key resource for implementation of weed biocontrol, with details of educational material and group involvement in agent rearing, release and monitoring.

Information on Natural Enemies

There are still very few good quality guides to natural enemy recognition and their use in IPM, especially in developing countries. One of the classics which has been translated into more than 20 languages is the International Rice Research Institute's pocket guide entitled 'Friends of the Rice Farmer' (Shepard *et al.*, 1987). A more recent book and slide set on natural enemies of vegetable pests in the USA has been produced by Cornell University with detailed, practical information on lifecycles, effectiveness and use in crops of native species and those mass produced for augmentation in the field (Hoffmann & Frodsham, 1993). Knutson & Ruberson (1997) on natural enemies in cotton and the University of California extension series on IPM for different crops (e.g. University of California, 1992) are also helpful guides to natural enemies and their role.

In developing countries, demand for information, especially colour pictures of natural enemies, is high among extension staff, educators and NGO field workers keen to promote the conservation of natural enemies in pest management. A colour booklet on natural enemies of the African bollworm *Helicoverpa armigera* (Hübner) (Lep., Noctuidae) in Kenya (van den Berg & Cock, 1993) has been requested from as far away as Zimbabwe, India and Venezuela. This demonstrates the lack of cheap, easy-to-read and accessible information on recognizing major groups of natural enemies in tropical cropping systems.

The majority of technical literature tends to be limited to long lists of species and genera recorded on certain pests in a particular area, written in scientific nomenclature unfathomable to most crop protection field staff, farmers, or indeed agricultural policy-makers. There has been an unfortunate and fairly widespread tendency for well-meaning scientists to use the same kind of language and technical terminology when attempting to write booklets on the usefulness of biological control aimed at extension and farming audiences, and the majority of texts on natural enemies assume a grasp of insect taxonomy well beyond the reach of most crop protection staff. One exception, however, is a recent book from Central America which aims to help the non-expert to recognize parasitoids of crop pests and begins with basic information on collecting and rearing parasitoids and an explanation of the taxonomic terms used (Cave, 1995).

One woefully neglected area of biocontrol education is in primary and secondary school curricula. By investing time and effort into educating our children about biocontrol and the natural enemies they can meet in the garden and on the farm, we can surely go some way to fostering a more critical attitude to pesticides in the next generation of farmers and politicians. Jeffords & Hodgins (1995) describes practical learning activities for eleven to fifteen year old pupils while some Australian weed biocontrol programmes have also included schools projects (Briese & McLaren, 1997).

Making Practical Use of Biocontrol Information

It is one thing to be able to recognize natural enemy groups in the field and to read about their feeding habits or parasitism rates, it is quite another to make active use of this new knowledge to increase the effectiveness of natural control of pests on a farm. To do so, you need to understand which farm management practices help or hinder existing natural enemies and relate these to your current farming methods. One of the very few popular-level guides, particularly in developing countries, which attempt to fill this gap, was published by an NGO promoting alternatives to agrochemicals and contains instructions on natural enemy augmentation and conservation methods for cotton, vegetables and fruit crops. (Valdivieso & Bartra, 1993).

The use of local languages for biocontrol awareness training is extremely important. Often there will be no local name for a particular natural enemy and farmers may be encouraged to invent their own names, based on what they have observed of the insect and what they have come to learn about its lifestyle. Table 1 gives examples of descriptive names developed by farmers for newly encountered 'farmers' friends' in three continents. Not only does this naming process help farmers to become familiar with the insects, but it can also give a real sense of ownership of the learning process and it's fun (Nyambo *et al.*, 1997). Children quickly pick up on these names too and their interest in biological control may be awakened to counteract the prevailing 'all insects are bad' ethos in many rural (and urban) communities.

Helping farmers to learn more about insect biology can result in the development of novel pest management techniques as farmers combine their own knowledge and experience with new information. Farmers participating in the Natural Pest Control Course run by Zamorano (the Panamerican School of Agriculture, based in Honduras) learned about natural enemies and about insect reproduction. The farmers subsequently used their new ecological knowledge to enhance predation of pests in maize, potatoes and vegetables, or to experiment with physical and cultural methods. Particularly important here is that because the farmers learned about principles, not just specific techniques, they were able to apply what they had learned to new situations as these arose. Furthermore, techniques adapted or invented by farmers were automatically uniquely matched to farmers' pest problems and resources in the way that more standard 'recipes' could never be.

Table 1: Names invented by farmers for key natural enemies

Farmers' name (in translation)	Natural enemy	Agroecosystem	Country	Source (pers. comm.)
vaccination wasp	various parasitic Hymenoptera	maize and beans	Nicaragua	C. Meir, 1994
helicopter insect	syrphid adults	aphids on brassicas	Kenya	Farmers' group, Karigu-ini, 1996
crocodiles	coccinellid larvae	cotton	China	J.Waage, 1997
"that which carries a heavy load"	chrysopid larvae of spp. which use prey debris as camouflage	brassicas and tomato	Kenya	M. Kimani, 1998
injected eggs	parasitized *Antestia* bug eggs	coffee	Kenya	M. Kimani, 1998

One hundred farmers sampled on average 18 months after the training had between them adopted 372 strategies, many of which the farmers had either adapted or invented themselves (Meir, submitted Ph D thesis). Examples of their biocontrol successes included: applying raw sugar to attract predatory ants into crops; spraying sugared water on crops to attract predatory wasps and ants; applying 'caterpillar soup' to beans to attract predatory wasps; transferring vespid wasp nests, parasitized caterpillars and earwigs to caterpillar-infested crops; not burning crop remains in order to conserve earwigs which prey on caterpillars in maize; heaping up crop remains and planting grasses to act as a refuge for natural enemies; placing maggot-infested potatoes onto ants' nests so that the ants ate all the maggots; use of chickens to control grasslooper caterpillars; cutting squash petals to allow natural enemies to search for boring pests hidden in the flowers; and educating children to distinguish pests from natural enemies and to collect the latter for field release (Meir, submitted Ph D thesis, Rodríguez, 1993, and Bentley *et al*., 1994). The effectiveness of the application of sugar water as a means of reducing pest damage in maize (via increased predation by natural enemies attracted by the sugar) was subsequently further evaluated by researchers (Cañas, 1996).

Understanding Disease Organisms and Biopesticides

Users of biopesticides need to appreciate that they are dealing with biological processes, if not living organisms, and are not merely applying a different type of chemical pesticide. The usefulness of several microbial agents has been severely compromised by poor understanding of their function. Unhappily, most of the marketing of biopesticides, particularly *Bacillus thuringiensis* (*Bt*), has encouraged their use as one-off biological versions of conventional pesticides (Waage, 1996). UV degradation of *Bt* commonly occurs when farmers spray it during hours of peak light intensity. IPM trainers have now developed exercises for farmers to assess for themselves the efficacy of *Bt* application at different times of day and to check the viability of commercial products before application (Vos, 1998).

Likewise, the effectiveness of the fungus *Beauveria bassiana* (Bals.) Vuill. against the coffee berry borer *Hypothenemus hampei* (Ferrari) (Col., Scolytidae) may be annulled by UV degradation or fungicide contamination of knapsack sprayers, the latter especially in areas where pesticide application is restricted to control of coffee diseases. If biopesticides are going to compete with chemical products, users should be able to assess the impact of the control agent if they are to be convinced of its value. Colombian coffee farmers interviewed in zones where *Beauveria* products are currently promoted specifically wanted to know how they can measure whether the fungus they apply is working in their plots and asked valid questions on its compatibility with parasitoid releases (Williamson, 1997). Neither of these issues have been fully addressed by coffee research or extension staff.

Farmers' lack of understanding of the mode of action of microbial control agents, or even the fact that they are living organisms, is not confined to poorly educated farmers in the South. A case in the UK glasshouse industry, where growers were using a new *Verticillium lecanii* (Zimm.) Viégas product (Vertalec®) to control aphid pests, resulted in complete failure for those growers who, despite label warnings, tank-mixed the microbial product with the fungicide benomyl (Quinlan, 1988). The product gained a bad name from just a handful of such cases and was eventually withdrawn from the market.

Limitations of Conventional Extension Methods

The classical mode of 'top-down' recommendations for pest control, transferred from researchers via extensionists, has frequently failed to reduce pest damage, or, indeed, pesticide use at farm level because researchers have been insufficiently aware of farmers' real problems and perceptions. Such recommendations have proved to be a particularly inappropriate mechanism for helping farmers to learn about the management complexities of IPM, for instance, in the case of exotic insect pests such as coffee berry borer, or for promoting the use of biological control. We have all heard anecdotal accounts of biocontrol promoters showing farmers enlarged pictures of parasitoids to be met with the response "No we've never seen giant wasps like that round here".

Nevertheless, research and extension colleagues all too often continue to use scientific terminology and message-laden approaches with farmers, failing to recognize that experiential learning is the best way to change attitudes and practices.

Dissatisfaction with the poor rate of adoption of agricultural technologies developed by scientists has prompted both questioning of the validity of the conventional top-down approach to agricultural research and development (R&D) and experimentation in alternative models using a range of farmer participatory methods. Research has shown that by involving the client or end-user in the planning, design, testing and evaluation of technologies, the technologies developed have a much higher probability of being purchased by consumers, or adopted, in the case of farmers (Merrill-Sands & Collion, 1994). Various Farmer Participatory Research (FPR) methodologies have been developed in which farmers and scientists work together to produce novel technologies, drawing partly on farmers' indigenous knowledge and innovativeness and partly on scientists' understanding of biological processes. FPR and other participatory approaches share a common emphasis on process, rather than product, and work to improve farmers' analytical and management skills. Here too, the majority of farmer participatory projects have been in natural resource management, with little attention to IPM or integrated crop management (Williamson, 1996). However, further evaluation of FPR and training methods in IPM across cultures and cropping systems, linked with training programmes for research and extension staff, is needed to provide a better understanding of how we can integrate biocontrol with other crop management options within a farming systems context. The potential of biocontrol for resource-poor farmers where pesticide use is minimal and where insect pests are minor constraints on production is a particular situation to be assessed.

Alternative extension approaches using non-formal education methodologies and participatory appraisal techniques where the emphasis is on group discussion, visualization of ecological and socioeconomic processes, problem diagnosis and problem-solving, have been used very effectively over the last two decades in a range of natural resource management fields (e.g. Hagmann *et al.*, 1997) although infrequently in pest management. The next section focusses on one of the most innovatory approaches to IPM training, with a strong emphasis on understanding natural enemies, which attempts to overcome many of the limitations of conventional technology transfer outlined above.

Discovery-learning for Biocontrol and IPM

One of the most impressive advances in biocontrol awareness-raising has been the development of the Farmer Field School (FFS) approach over the last decade, as a training method to help farmers step off the pesticide treadmill. The success of the FFS approach lies in its focus on the farmer as the key decision-maker in pest management and on the facilitation of a discovery-learning process using non-formal education methods. The field is the primary classroom and the four major principles are:

- Grow a healthy crop
- Observe fields weekly
- Conserve natural enemies
- Farmers understand ecology and become experts in their own fields

Box 1. Cage exclusion of natural enemies in the field.

Objective: To study the impact of natural enemies on sucking arthropod populations

Materials needed:

Vegetable field with aphids infestation
Nylon mesh
Bamboo sticks

Procedure:

Prepare ten nylon mesh cages (dimensions for cabbage 50 × 50 × 70 cm), supported by four bamboo sticks to cover individual plants.

Select ten plants with high numbers of aphids. Randomly label five of the plants as 'without predator' and five as 'with predator'. Remove all predators from the 'without predator' plant and the soil underneath, and cage each plant. Bury the nylon mesh carefully into the soil to prevent access of any insects (ants may gain access through small crevices in the soil).

Sample and transfer four active predators to each 'with predator' plant (choose large coccinellid larvae or large syrphid larvae). Cage each plant.

Observations:

After four days, remove the cages. Carefully count the aphids on each plant in each treatment, and record whether the introduced predators are still alive. Calculate the average number of aphids in each treatment.

Discussion:

How many aphids were found on the different plants in the different treatments?
What can we conclude about the role of predators in the field?

There are no standard recommendations or packages of technology offered. In the FFS, farmers observe a sample of crop plants in the field of one of the participants in order to collect data on pests, diseases, beneficials and the general condition of the plants. The observations are recorded visually by the farmers who draw an agro-ecosystem analysis poster. This is then used to facilitate a group discussion of the management practices which need to be carried out, according to the field results. By comparing plots under conventional chemical control, as practised by local farmers, with plots where pesticide application and other management practices are under IPM decision-making by the group, participants see the consequences and costs of calendar spraying for themselves over the course of an entire crop season. Discovery-learning exercises and other experiments are also used to help farmers learn about ecological processes. These include studying pest and natural enemy behaviour and lifecycles by keeping specimens in jars or cages known as 'insect zoos'; assessment of the effects of pesticides on natural enemies; simulated foliage damage experiments to explore plant compensation for pest damage; and simple parasitism and predation studies. Box 1 gives an example of the discovery-learning exercises which form a key element of the curriculum of FFS. Vos (in press) provides a useful summary of the FFS approach and methods in decision-making for vegetable IPM.

The impact of FFS in reducing pesticide use and hence pest resurgence problems has now been well documented in rice systems (Matteson *et al.*, 1994) where an abundant natural enemy fauna exists and where farmers had been tempted to spray against highly visible but economically unimportant leaf-feeding pests. In the rice system conservation of natural enemies is the central biocontrol strategy. The approach is proving equally valid in cropping systems where the action of native natural enemies alone is insufficient to prevent economic losses, often where pests are exotic. Through a Farmer Field School IPM training programme for highland vegetables in the Philippines, farmers took part in releases of the diamondback moth parasitoid *Diadegma* sp. in their cabbage terraces and built simple wooden emergence boxes, which they dubbed "Diadegma hotels", in which to place parasitized cocoons distributed by the local university. From their observation of parasitized diamondback moth larvae and exercises demonstrating the effects of commonly used insecticides on the parasitoids, participating farmers began to question visiting agrochemical salesmen on whether the products they were pushing were "Diadegma-friendly". Since 1994 over 1700 farmers have been trained in vegetable IPM at 65 FFS sites. Before the FFS project, farmers in the region were applying an average of 14.6 litres of pesticide applications and they have now decreased insecticide use by 80% to 2.9 litres (ADB, 1996). Instead of their previous reliance on broad spectrum insecticides, farmers are now using *Bt* on a needs basis if *Diadegma* and other mortality factors alone are not enough to keep diamondback moth in check. Farmers now rely much less on information from pesticide salesmen and more on their own experiences shared during FFS sessions (Anon., 1998).

A recent FFS pilot project in Pakistan was undertaken to tackle the problem of increasing insecticide use in cotton and the resurgence of the whitefly *Bemisia tabaci* (Gennadius) (Hom., Aleyrodidae), which vectors cotton leaf curl virus (Poswal & Williamson, 1998). Research has shown that whitefly may be kept under good natural control by a natural enemy complex composed of five species of parasitic wasp, lacewing and ladybird predators and a fungal pathogen similar to *Paecilomyces* spp. The current whitefly outbreaks in Pakistan therefore appear to be a direct result of the elimination of these key natural enemies in cotton fields due to increased and early insecticide application in cotton. However, for farmers to gain the confidence to abandon preventative calendar applications and to make their own decisions based on farm-specific needs, considerable understanding of agroecological processes is required, particularly of the role of natural enemies of cotton pests and cotton plant physiology, and plant compensation for insect damage. The FFS pilot project therefore developed curricula for both the Training of Trainers (TOT) and FFS in the specific context of cotton pests and natural enemies in Pakistan. Box 2 lists the topics and experiments conducted.

As a consequence of learning about natural enemies and crop compensation, the farmers who took part in the Pakistan FFS did not apply any insecticides on any of the IPM decision-making plots in the first 8-10 weeks after planting, thus allowing natural enemy populations to build up. The average number of applications in the IPM plots was 1.4, compared to 5.2 in the Farmers' Practice plots, where the group applied the current chemical controls used by farmers in the area. IPM plot yields averaged 1363 kg/ha and Farmers' Practice plots averaged 1245 kg/ha. All FFS participants observed whitefly parasitization by *Encarsia* and *Eretmocerus* spp. (Hym., Aphelinidae), predation of jassids by mites, ants and spiders, and of whitefly by anthocorid and reduviid bugs, spiders and staphylinid beetles. In addition to small insect zoos in plastic bags, all sites also set up field cages to observe spider predation on jassids. After experimenting with whitefly resurgence after organophosphate application, one FFS group even demonstrated the impact of unnecessary application to local agrochemical salesmen, Department of Agriculture officials and neighbouring farmers.

In Africa, FFS training programmes are focussing on the mixed cropping systems typical of smallholder farms and on broader crop management including soil fertility and water conservation, the key issues in improving income and sustainability of subsistence farms. Nevertheless, awareness-raising about natural enemies remains a valid part of the curriculum, even in systems where pesticide use is minimal or non-existent. For example, smallholder organic farmers in a Kenyan FFS project came to appreciate the value of predators and parasites in controlling pests and to understand the consequences of various management practices on these natural enemies. They observed higher numbers of parasitized *Antestia* (Het., Pentatomidae) bugs (a pest which sucks and damages developing coffee berries) in their IPM coffee plots which were well pruned, compared to the levels in their Farmers' Practice plots where bushes are largely left unpruned (Nyambo et al., 1997). In Zimbabwe, participants in a TOT/FFS programme for mixed cotton systems in marginal areas have recently discovered new information about natural enemies of cotton pests in their country, including an effective thrips predator of spider mites and an unrecorded coccinellid beetle (K. Gallagher, pers. comm.). These examples show that a discovery-learning approach in farmer participatory IPM training not only empowers farmers to make active use of biological control in their fields but may also make positive contributions to the knowledge base on natural enemies and their impact in little-studied systems.

Box 2. Curricula for Farmer Field School (FFS) and Training of Trainers (TOT) cotton IPM training courses in Pakistan.

- whitefly (*Bemisia tabaci*) parasitization studies
- natural enemy action thresholds for adults and larvae of pink, spotted and American bollworms (*Pectinophora gossypiella*, *Earias* spp. and *Helicoverpa armigera*)
- natural boll shedding studies
- impact of bollworm and bollworm predators during square shedding and early boll formation
- yield loss studies for bollworms and defoliators
- insect zoos for whitefly and jassids with *Encarsia*, *Eretmocerus* and *Trichogramma* spp. of Hymenoptera; lacewings; coccinellids, staphylinids and carabids; geocorid, reduviid and anthocorid bugs; and oxyopid spiders

Experiments included:

- cotton varieties resistant to CLCV (cotton leaf curl virus)
- whitefly population growth studies
- pesticide effects on livestock and natural enemies
- defoliation and desquaring experiments

Special topics for the TOT only included:

- neem oil on pests and beneficials, compared to organophosphates
- cotton soil fertility and structure and nutrient management
- nuclear polyhedrosis virus (NPV) for American bollworm control
- cotton diseases
- organic cotton
- *Trichogramma* releases, benefits and risks
- pheromones for cotton pest control
- cotton physiology - flower and fruit shedding and role of herbivores (jassids and spotted bollworms as beneficials)

The curricula for both TOT and FFS also included group dynamics and perk-up exercises and games to build team spirit, to gain confidence in non-formal education methods and to encourage self-evaluation.

The FFS approach actively encourages farmers to carry out their own research into biocontrol and other aspects of IPM too. Ooi (1998) recounts how Mr Pak Oyo, a rice farmer from Indonesia, observed dragonflies perching on bamboo stakes around his rice nursery and used his knowledge of predation and experimentation refined during FFS training to set up his own study. He assessed dragonfly and brown planthopper (*Nilaparvata lugens* Stål; Hom., Delphacidae) numbers using different bamboo stake layouts and timings to see whether the perches attracted more dragonflies into his rice fields. Convinced of the usefulness of Pak Oyo's conservation biocontrol method, local farmers are now planting 40 ha of paddy with bamboo perches in the current season.

The group discussions and active experimentation, which are key elements of the approach, give FFS participants the motivation and confidence to apply their knowledge and skills to new crop or pest situations after the training has finished. Kenyan FFS vegetable farmers, for example, who had studied brassica and tomato pests and their natural enemies, adapted their agroecosystem analysis observations and knowledge of pesticide effects on 'friendly insects' to decide how to tackle an unfamiliar podboring pest on dry beans in the following season (M. Kimani, pers. comm.).

Influencing the Policy-makers

The previous sections explored progress in making farmers more aware of natural enemies and in how this knowledge can be used to encourage the implementation of biological control as the cornerstone of IPM.

Successful implementation of IPM needs to focus not only on field research and farmer training from a farmer-first perspective, but also on raising biocontrol and IPM awareness among government and other decision-makers responsible for pesticide registration and regulation. For example, a recent International Organization for Biological Control initiative on evaluation of pesticide effects on natural enemies in Asia included a training workshop for pesticide registration officers and researchers to learn standard ecotoxicological testing methods for beneficial arthropods and to develop appropriate protocols for key crops where pesticide use is currently incompatible with IPM. Work is now underway to collect natural enemy and pesticide data in rice, vegetables and fruit crops and to use this information to feed into national pesticide registration schemes (Williamson, in press).

The success of the FFS training programme in the Philippines has influenced local government decision-makers of the value of biological control to such an extent that the mayor of Atok town in the Cordillera region recently banned all advertising of chemical insecticides in his municipality (Cimatu, 1997). This is the kind of policy change that can make a profound difference to the biocontrol promotion we are involved in at research or training level.

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