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INSECT PEST MANAGEMENT IN TROPICAL ASIAN IRRIGATED RICE

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■ **Abstract** Abundant natural enemies in tropical Asian irrigated rice usually prevent significant insect pest problems. Integrated pest management (IPM) extension education of depth and quality is required to discourage unnecessary insecticide use that upsets this natural balance, and to empower farmers as expert managers of a healthy paddy ecosystem. Farmers' skill and collaboration will be particularly important for sustainable exploitation of the potential of new, higher-yielding and pest-resistant rices. IPM ‘‘technology transfer’’ through training and visit (T&V) extension systems failed, although mass media campaigns encouraging farmer participatory research can reduce insecticide use. The ‘‘farmer first’’ approach of participatory nonformal education in farmer field schools, followed by community IPM activities emphasizing farmer-training-farmer and research by farmers, has had greater success in achieving IPM implementation. Extension challenges are a key topic for rice IPM research, and new pest management technology must promote, rather than endanger, ecological balance in rice paddies.

INTRODUCTION

Pest management in rice, *Oryza sativa* L., was last addressed in these pages in 1979 (88). Although much has changed since then, Kiritani correctly foresaw today's priorities:

> The implementation of pest management by farmers still remains far behind. To bridge this apparent gap, it is anticipated that many obstacles should be conquered not only in technology but also in socioeconomic sectors.

The primary focus of this review is integrated pest management (IPM) implementation, customarily considered the domain of extension science, although this account opens with a summary of key advances in IPM technology. Today's rice IPM strategies can be said to have matured, in that they reflect a more sophisticated appreciation of the structure and dynamics of paddy ecosystems (90). Their implementation involves greater farmer participation, with research by scientific institutions and farmers playing a dynamic supporting role.

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This review concerns irrigated rice in tropical Asia, the source of approximately one third of the world's rice (75) and the arena in which key developments have taken place. Pest management research and experimentation with different extension approaches have resulted in an IPM effort in that agroecosystem that is the largest and arguably the most innovative in the world. This review does not cover postharvest pest management, temperate rice, non-irrigated rice, or other crops and regions, except to enlarge upon specific points. Rather than attempting to review all ongoing work and cumulative literature since 1979, this review addresses important present and future directions in implementation and research. The educational principles and methodologies, as well as the training strategy, applied in Asia for rice IPM are now being used in other crops and on other continents (44a). Moreover, they are relevant to extension covering all aspects of agriculture, not just IPM in crop production.

THE MATURATION OF RICE IPM

Formerly, as described by Kiritani, control of rice insect pests was considered a central problem for Asian rice farmers. Yield losses of 15% to 25% or more were (and sometimes still are—see 108), attributed to ''an abundance of pests'' (88). Two or three crops a year, often overlapping, of heavily fertilized monocultures of ''Green Revolution'' high-yielding cultivars were considered a vulnerable pest breeding ground. Developing strongly pest-resistant rice cultivars was a high priority, but these were threatened by ''resistance breakdowns,'' particularly to the brown planthopper (BPH), *Nilaparvata lugens* (Stål). Although the problem of insecticide-induced secondary pests (notably BPH) was recognized and attributed to the destruction of natural enemies, insecticides used according to economic thresholds were considered a valuable complement to varietal resistance and synchronized planting as the basis for integrated control (88).

Today's view of the irrigated tropical rice ecosystem and corresponding recommendations for insect pest management, summarized by Way & Heong (158), represents a radical revision of previous ideas regarding losses to insect pests and the role of insecticides. Insecticide use is considered destructive under most circumstances, and not a fundamental component of rice IPM. Instead, successful IPM depends on farmers' understanding of, and confidence in, resistance and tolerance to pests in a healthy crop protected by naturally occurring biological control. Action thresholds for insecticide use that are developed by researchers are irrelevant and should be discarded.

Crop Loss Assessment Revisited

Much of the previous attribution of high yield losses to insect pests is now considered an artifact of overestimation based on worst-case scenarios, short-term, small-plot trials at single sites frequently unrepresentative of farmers' field conditions, and misunderstanding of the effects of insecticides on paddy ecology (126). This reassessment highlights pest-related risk and the representativeness of crop loss data as researchable topics (21, 131).

Changed field conditions, including less insecticide use by farmers in some regions (e.g. 61, 119), and new rice cultivars (53), may have reduced yield losses to pests. Unstable, relatively high-level single-gene resistance has been deployed against BPH, green leafhoppers *Nephotettix* spp., and the gall midge *Orseolia oryzae* (Wood-Mason) (158). Minor resistance to BPH is also operative (18). Stem borer damage, especially by the yellow stem borer *Scirpophaga incertulas* (Walker), is ubiquitous and variable, but generally minor (31, 77). Current estimates of yield losses to stem borers have declined (158). This decline may be due to the moderate, seemingly polygenic resistance of many modern rice cultivars, and their ability to compensate for stem borer damage by increases in tillering, percentage productive tillers, and grain weight (129, 130).

Resistance breeding has had relatively little success against leaf feeders, however (85, 158). Despite that lack of varietal resistance, and although leaf-feeding insect damage is highly visible, leaf-feeding insects do not appear to cause significant yield loss under most circumstances. For instance, no yield loss was detected when up to 60% of leaves were damaged by whorl maggot (*Hydrellia* spp.) (142). Similarly, up to five larvae/hill of the leaffolder *Cnaphalocrocis medinalis* (Guenée) may damage as many as 50% of leaves (26), but Japonica rice at the tillering stage can compensate for as much as 67% of leaffolder-damaged leaves (104), and computer simulations show that leaffolder densities must reach 15/hill before any detectable yield loss results (35). Such findings indicate that farmers' common practice of early-season insecticide sprays against stem borers and defoliators is usually unnecessary (55, 123, 158).

Reliance on a Balanced Paddy Ecosystem

Food web studies (e.g. 58, 59, 72, 125, 135, 136), and investigations of predator and parasitoid biology, ecology, and impact (e.g. 26, 80, 155) have highlighted the biodiversity of rice paddy fauna, including natural enemy richness (6, 110, 140, 141, 153). Most rice pests are controlled by a complex and rich web of generalist and specialist predators and parasites that live in or on the rice plant, paddy water, or soil. Abundant early-season detritivores and plankton-feeders such as Collembola and chironomid midge larvae allow generalist predators to establish and multiply in unsprayed paddies before herbivores immigrate (139, 162). If undisturbed, these natural enemies normally prevent significant insect pest problems.

Early-season insecticide applications destroy that ecological balance. Insecticide wipes out predators along with their food supply, leaving the field open for pest buildup (5, 17, 64a, 134, 139). Insecticide suppression of natural enemies, particularly spiders, predacious water striders in the genera *Microvelia* and *Mesov-*

elia, and the mirid bug *Cyrtorhinus lividipennis* Reuter, has been confirmed as the key factor in the emergence of BPH as a secondary pest (54, 83, 112).

Instances in which natural control fails in untreated crops are not well enough understood. Insecticide use is not the only factor that may perturb the paddy ecosystem. Unusual weather patterns and/or migratory behavior are frequently associated with outbreaks of sporadic pests such as the rice hispa *Dicladispa armigera* (Olivier), the rice thrips *Stenchaetothrips biformis* (Bagnall), armyworms [*Spodoptera mauritia acronyctoides* (Guenée), *Mythimna separata* (Walker)], and black bugs (*Scotinophara* spp.) (22). Some rice insects are major pests in only one region—hispa in Bangladesh (4) and thrips in Vietnam, for example—and this raises the question of possible geographical variation in associated natural enemies (114a).

Because most insect pests of tropical rice are indigenous and have coevolved with a rich natural enemy fauna, attempts at classical and inundative biological control have generally been fruitless. Attention has turned to conserving existing natural enemies and maximizing their impact (114). In contrast to earlier advocacy of large-scale, synchronized planting with long fallow periods for controlling pests (e.g. 96, 109), some ecologists are recommending continuous, staggered planting that keeps natural enemies in mature rice within easy immigration distance of new crops (78, 132, 139, 156).

Although resistant cultivars and biological control are generally considered compatible, interactions between cultivars and natural enemies may be positive or negative (11). For example, volatile chemicals produced by certain rice genotypes can attract BPH predators (122). The influence of cropping practices and nonrice habitats—particularly bunds and field edges—on pest infestations and natural enemy biodiversity, numbers, and impact is being examined with a view to identifying better management options for farmers (e.g. 16, 94, 137, 159, 163, 164).

Aside from causing secondary pest problems, insecticide use is believed to have accelerated the adaptation of BPH to resistant varieties by favoring the survival and reproduction of virulent individuals (44, 51). In this regard, it is important to note that past extension efforts failed to instill the understanding and confidence necessary for farmers to take advantage of varietal resistance. For example, in 1992 most farmers in three villages in Central Luzon, Philippines, planted the BPH-, green leafhopper- and stem borer-resistant rice cultivar IR64, but named those pests as the main targets of their insecticide applications (115).

Economic Thresholds Reconsidered

Numerous studies indicate that in tropical Asia irrigated rice farming without insecticides is economically competitive (e.g. 31, 81, 100, 115, 144, 157). When human health and environmental costs of insecticide application are considered (89, 95, 120), "no action" appears to be the wisest pest management option (126).

Farmers who do not drop insecticide use altogether are hard pressed to identify the infrequent occasions when it will be profitable to spray.

Economic threshold levels as promulgated by researchers and used by surveillance and alert systems are not useful under most circumstances. At worst, they alarm farmers without reason and pressure them to apply insecticides unnecessarily. At best, they provide a forecast that farmers must second-guess, because general observations and thresholds are not sufficiently farm and locality specific. In practice, farmers decide for themselves whether pest control action is warranted, based on a more refined process that takes into account the condition and priority of their individual crop, as well as other factors such as the current prices of rice and insecticide, and options for more productive alternative expenditures (56, 101).

IMPLEMENTING RICE IPM

Now that many IPM specialists have arrived at a radically different message—''insecticides are usually not needed in rice''—and are focusing on a strong crop in a healthy paddy ecosystem, they have the difficult task of undoing the effect on farmers of decades of exhortations to rely on pesticides. Advocacy of pesticide use, reinforced by extensive agrichemical advertising, led both farmers and policy makers to overestimate crop losses caused by pests, and the effectiveness of insecticides (157). Unless they understand the benefits of avoiding unnecessary insecticide use, farmers tend to overreact to slight infestations and make routine preventive applications (32).

Twelve percent of pesticides sold worldwide are applied to rice crops, and no other single crop accounts for as much pesticide use (161). Rice farmers will continue to be the target of massive agrichemical industry marketing and promotion that is supported by financial resources dwarfing those of agricultural extension programs. If farmers are to have the understanding, skills, and confidence to withstand that barrage, IPM training must have depth and quality, and appropriate long-term technical support must be available afterward.

Rice IPM extension in Asia has evolved over two decades. Advances have drawn heavily on social science expertise and the incorporation of techniques developed in other fields of endeavor, notably commercial advertising, participatory nonformal education, and community organizing (101). Changes in people's roles in communications and in education during this evolution reflect a paradigm shift in agricultural development.

Scientific paradigms are universally recognized scientific achievements that, for a time, define scientists' view of nature and offer model problems and solutions to a community of practitioners. When novel experience or knowledge becomes incompatible with the prevalent paradigm, a ''paradigm shift'' results in a new view of the world in which scientific work is done (91). Current IPM extension approaches reflect two paradigms. The ''technology transfer'' paradigm proved unsuitable for farmer education but can motivate pesticide use reduction with a simple message. Under the ‘‘farmer first’’ paradigm, IPM extensionists seek to lay the educational foundation for farmer-led community development through farmer field schools and community IPM.

Developing IPM Training Principles

Interdisciplinary research facilitated by the International Rice Research Institute (IRRI) in the Philippines from 1978 to 1980 (46–48, 93) developed basic rice IPM training principles:

1. Group training so that farmers can learn from each other, with frequent discussions and group reinforcement of decisions.
2. A curriculum pared down to essentials and simplified, having the most important points repeated often.
3. Twenty to 40 hours of good-quality instruction in the rice paddy, distributed so that farmers can practice skills and crop protection decision-making each week during an entire growing season.
4. Class experiments and demonstrations that engage farmers’ curiosity and encourage imaginative inquiry and self-reliance.
5. Periodic followup as farmers gain confidence in their independent decision-making.

Training on a pilot scale in the Philippines according to those guidelines, with highly motivated, intensely supervised field officers using conventional training methodology, made substantial long-term impact (81, 84).

The Asian rice IPM training effort has received long-term technical and financial assistance from the United Nations Food and Agriculture Organization (FAO) Intercountry Programme for Integrated Pest Control in Rice in South and Southeast Asia, recently renamed the FAO Programme for Community IPM in Asia. This program, hereinafter referred to as the FAO IPM Program, provides coordination, technical support, and training to national IPM extension and research initiatives, and currently includes 12 member countries (34, 40). In 1984, FAO increased its support to several countries in order to reach more farmers with the training approach that had been proven effective on a relatively small scale in the Philippines.

Technology Transfer

Under the longstanding ‘‘technology transfer’’ paradigm, agricultural research and development are carried out stepwise by a large, multipurpose hierarchy. Recommendations for farmers are defined after several stages of research, which takes place largely on experiment stations. Instructional messages about the resulting technical packages pass through a chain of extension officers to a subset of farmers, who are supposed to communicate the recommendations to their neighbors.

These systems have historically promoted the use of fixed ‘‘packages’’ of purchased inputs including pesticides, with or without threshold levels governing pesticide application. Insecticides are commonly subsidized, and recipients of government credit are often required to purchase a certain quantity of pesticides each season (84, 124). Decades of such programs entrenched a chemical-dependent attitude in farmers and government agriculturalists alike.

Training and Visit Extension The ‘‘technology transfer’’ model has been widely implemented in the form of the Training and Visit (T&V) Extension System promoted by the World Bank, long the only source of credit for major extension projects. The T&V system is a set of principles developed for increasing the effectiveness of technology transfer: improving management, fostering professionalism, providing regular training for extension agents, and preserving a strong field orientation stressing regular (biweekly) visits to farmers (8). With FAO IPM Program support in the late 1980s, Philippine master trainers presented field IPM implementation courses for selected T&V staff from Sri Lanka, Indonesia, and new areas in the Philippines. Then IPM extension responsibility was handed over to those countries’ national T&V systems, supported by strategic mass media campaigns.

The strongly hierarchical T&V extension model conditioned the style and content of training at all levels. Trainer and trainee related to each other through the traditional teacher/student relationship and the corresponding conventional training methodology: The trainer as ‘‘expert’’ dominates, defining the curriculum and tending to lecture, trainees are expected to be interested, deferential, and accepting. Extension officers are usually trained in the classroom between cropping seasons, with little opportunity for hands-on field practice. The curriculum does not emphasize teaching skills because the accent is on periodic message delivery. As a result, extension agents emerged ill-prepared for their job of helping farmers, including their duty to pass farmers’ messages ‘‘bottom-up’’ back to researchers. In practice, ‘‘technology transfer’’ is a ‘‘top-down’’ approach with ‘‘experts’’ in charge and with little feedback from below. That situation is commonly exacerbated by a lack of incentives and rewards for good work by village-level extensionists (3, 12, 45, 145, 149). Extension training under this paradigm fails to motivate field extension agents and farmers because it is unresponsive to their actual needs and ideas.

Indeed, rice IPM implementation in Asia failed under the ‘‘technology transfer’’ paradigm despite T&V management improvements, FAO technical support, and, in some cases, top-level willingness to be flexible and to initiate special activities to duplicate the IPM training approach that succeeded originally in the Philippines. Inertia, indifference, and extension agents’ many conflicting responsibilities precluded the necessary intensive, high-quality field training effort. As a result, farmers’ pest management practices did not change appreciably (101, 160; PC Matteson & H Senerath, unpublished data). Similar experiences in other crops and regions (e.g. 2, 13) support the conclusion that traditional technology transfer practices are unsuited to IPM.

Strategic Extension Campaigns Strategic extension campaigns (SECs) using mass media (1) have been more effective than T&V as an element of ‘‘technology transfer’’ programs. They convey research findings and recommendations in a simplified form in order to motivate attitude change. SECs can achieve rapid impact because they reach most farmers in an area all at once, including remote locations normally not visited by extension trainers.

Analysis of farmers’ IPM attitudes, knowledge, and decision-making processes (105–107) has been applied to SEC planning. A number of SECs on IPM themes were carried out in Asia during the 1980s. Evaluation surveys indicate that they improved farmers’ knowledge, attitudes, and practices, often strikingly, and that they can rectify misconceptions that prevent farmers from making good pest control decisions (1, 33, 66, 116). SEC materials concerning pesticide use must be planned with particular care, however. Campaign results indicate that long exposure to intensive pesticide advertising can condition farmers to react to any image of pesticide use as a recommendation, regardless of the accompanying message (32).

Motivation by Mass Media Currently, ‘‘Forty Days’’ SECs are being fielded in several countries in order to reduce unnecessary insecticide use in early-season rice. The objective is to rectify farmers’ mistaken belief that leaf-feeding insects, particularly leaffolders, cause severe yield loss. This belief leads them to apply insecticides during the early stages of the crop, endangering applicators (126) and often triggering outbreaks of BPH and other secondary pests (63).

The Forty Days campaign conveys a heuristic, or simple rule of thumb (79), that summarizes a large volume of research findings and simplifies decision-making: ‘‘Spraying for leaffolder control in the first 40 days after planting (or 30 days after transplanting) is not necessary’’ (61). Such messages, which are at odds with farmer’s beliefs, provoke cognitive dissonance (41), psychological conflict that can be resolved through reevaluation (25). To encourage reevaluation, the campaign includes an element of farmer participatory research. Skeptical farmers are urged to test that decision rule with a field experiment, leaving about 500 m^2 of rice field unsprayed and then comparing the yield with that of sprayed rice.

This approach to insecticide use reduction was first tried out on a pilot scale, via interpersonal contact between researchers, extensionists, and farmers rather than via mass media. In Leyte, Philippines in 1992, 101 farmers presented and discussed their experimental results in end-of-season workshops. Workshop participants concluded that early-season insecticide applications could be dropped without affecting rice yield, and this conclusion changed their beliefs, practices, and profits (62). Previously, most farmers believed that leaf-feeding insects cause severe damage (77% of farmers) and yield losses (87%), and should be sprayed for early in the season (62%). After the experiment, 28%, 9%, and 10% of farmers, respectively, held those beliefs. The proportion of farmers who applied insecticide during the first 30 days after transplanting dropped from 68% to 20% after one year, and to 11% after two years. Average insecticide applications per season dropped from 3.2 to 2 in two years. The average seasonal cost of insecticide/ha was reduced accordingly, from $17.10 to $7.60 (60). Similar results were obtained in the Mekong Delta in southern Vietnam (64).

Mass media—radio dramas and the distribution of posters and leaflets—were subsequently used in conjunction with farmers' meetings and demonstrations to implement Forty Days campaigns in the Mekong Delta. A media campaign in Long An province initiated in late 1994 with an audience of 20,000 farm families prompted 56% of farmers to perform the experiment. A year later, the typical number of seasonal insecticide applications was reduced from three or four to one or two although leaffolders and other leaf-feeding insects remained the chief targets. The proportion of farmers applying their first insecticide application within six weeks of planting had dropped from 96% to 62%. The proportion of farmers believing that early season spraying is needed for leaffolders fell from 77% to 17% (61).

Farmer First

In response to the failure of IPM technology transfer by T&V extension, the Indonesian National Programme for the Development and Training of IPM in Rice-Based Cropping Systems, supported by the FAO IPM Program, developed a more dynamic, self-replicating IPM training process. The training is carried out in Farmer Field Schools (FFSs), which retain the rice IPM training principles and season-long framework first elaborated in the Philippines, and add participatory nonformal education methodology to motivate and empower farmers (82, 117, 127, 128). This new training process is based on changed roles for farmers and trainers, reflecting a more recent agricultural development paradigm called ''farmer first'' (15, 138).

Proponents of ''farmer first'' argue that conventional top-down agricultural research and extension methods usually fail to produce appropriate innovations, and that best results are achieved when farmers are instrumental in every step of the process. Under this model, farmers, extension agents, and researchers work together as equal partners, each having specialized skills and knowledge to contribute. The latter two become collaborators, facilitators, and consultants, empowering farmers to analyze their own situation, to experiment, and to make constructive choices (29, 42, 43).

Farmer Field Schools In a typical weekly half-day Farmer Field School (FFS) session, about 25 farmers divide into groups of five to analyze the rice agroecosystem and decide what the crop needs that week. The situation in an ''IPM

Practice'' plot is compared to that in a ''Farmer Practice'' plot where customary preventive insecticide applications are made. While the farmers are observing the crop, the trainer facilitates a participatory ''discovery'' learning process. Farmers' questions are answered with other, leading questions that help them draw on their own knowledge and experience, or trainers help farmers design and carry out field experiments that fill information gaps. Each small group makes a drawing of the rice ecosystem that illustrates the condition of the paddy and the rice plant, along with associated pests and their natural enemies. This diagram helps group members analyze ecological interactions and draw conclusions about crop needs, which are presented to the larger group. A plenary decision is hammered out via extensive discussion that reinforces learning while allowing trainers to evaluate trainees' progress and to correct misunderstandings.

After this agroecosystem analysis process is completed, a special topic appropriate to the stage of the crop is taken up. Complementary group dynamics exercises provide fun, enhance learning, and reinforce farmer solidarity and collaboration.

The FFS curriculum focuses on community ecology and dynamics in the rice paddy, with emphasis on the natural enemies of pests. Learning more about natural enemies, often via ''insect zoos'' that allow farmers to observe predation and parasitism in action, is at once the most enjoyable and the most powerful FFS activity for farmers. With this new knowledge, they understand clearly why unnecessary insecticide use, so harmful to their ''friends,'' must be avoided (111).

Farmers make crop management decisions based on their personal circumstances and the ecological balance in each paddy. The four IPM implementation principles of the Indonesian national program reflect this holism and the IPM goal of making farmers confident managers and decision-makers, eager for new ideas and information but free from dependence on a constant stream of pest control directives from outside:

1. Grow a healthy crop.
2. Observe fields weekly.
3. Conserve natural enemies.
4. Farmers are IPM experts.

Improved results in Indonesia and subsequent comparative studies of training methodologies and their impact indicate that FFSs are more effective for IPM training than conventional extension approaches, which generally still focus on economic thresholds for pesticide application (99, 150). A followup study of the first 50,000 Indonesian FFS graduates found that they reduced insecticide application from an average of 2.8 sprays per season to less than one, with most farmers not spraying at all. When farmers did apply insecticide, they could identify a specific target pest (118).

A 1993 Philippine Barangay IPM Project in Central Luzon found that both FFSs and the Forty Days approach reduced the proportion of rice farmers using insecticides from 80% to less than 20%, with no yield loss. This change in farmers' behavior lasted at least four years in each case (115).

Insecticide use reduction is only one of many agroeconomic impacts of FFSs, however. FFSs address all aspects of production, including optimal seeding rates and fertilizer application. In general, rice FFS graduates' profits rise because their insecticide and seed costs decrease while yields are as high as or higher than before, due to better crop management. For example, FFS participants in the Bangladesh Integrated Rice and Fish (INTERFISH) project of CARE, a large international nongovernmental organization, use no pesticides and are harvesting 17% to 33% more rice, which increases their gross marginal income by 33% to 54%. In their rice/fish systems, made possible by eliminating insecticides, those higher rice yields are maintained, but income increases by 96% to 387% (9). Moreover, yield variance typically decreases, reflecting lower production risk—an important consideration for farmers who rely on growing rice for their livelihoods (Vietnam National IPM Programme, unpublished data). Learning and practicing problem-solving skills for IPM enables farmers to continue learning from the field and from the consequences of each management decision from then on. The result is better cropping practices and management expertise, which are then applied to other crops and production systems (82, 97).

In the past, impact evaluations of IPM extension programs confined themselves to quantitative agroeconomic indicators. Because FFSs and post-FFS followup activities have broader objectives than IPM, however, the range of relevant indicators is much broader, and the indicators are qualitative as well as quantitative. Participation and empowerment are not just ways to improve farmers' production practices; rather, they are the goal. Therefore, indicators of increased access, leverage, status, and choices for farmers, such as farmer innovations and the degree to which farmers control the IPM agenda and act to affect policy, are important (J Pontius, unpublished data). Case studies are useful for presenting qualitative as well as quantitative evaluation findings (38, 39).

Community IPM National and local extension systems are seeking to insure the sustainability of IPM implementation. It is considered important that farmers acquire the necessary skills to establish and maintain local IPM programs. The FAO IPM Program is supporting training of Asian IPM officers in participatory planning methods. Farmer graduates of FFSs, assisted by trained IPM personnel, carry out planning exercises for followup activities at the subdistrict level, then implement the plans that they make (38, 39). This community IPM development process is most advanced in Indonesia and Vietnam. By presenting their plans to government officials up to the provincial level, farmers establish a dialogue that reinforces their role as planners, secures local funding for IPM, and is meant to lay the foundation for effective, long-term government support to farmer-led initiatives (69, 70, 82).

The broad range of resulting activities has deepened farmers' ecological understanding, strengthened FFS alumni groups, and helped them find ways to involve other farmers (38, 39). Examples include:

1. Followup FFS in rice with in-depth studies of special interest, such as rice-fish production.
2. FFS for other crops (e.g. vegetables, soybeans, tea).
3. FFS for elementary school students.
4. Farmer IPM clubs, congresses and technical meetings.
5. Marketing of "green label" pesticide-free rice.
6. IPM consultant teams.
7. Irrigation system improvement.
8. The organization of cooperatives.
9. Action Research Facilities for farmer-led experimentation (see Research Models section below).

Especially in Indonesia and Vietnam, FFS graduates who show ability and enthusiasm for involving others participate in a week-long training-of-trainers course and then conduct their own field schools. Farmer Trainers are supported by periodic visits from IPM staff and by trainer workshops conducted at least three times per season for discussing leadership and FFS issues. In addition, they have access to case studies of IPM innovations, documented with extension materials, that can enrich a community's IPM program. They also represent their local farmer groups in farmer planning meetings and farmer technical meetings that help institutionalize farmer-based extension (69, 70).

Quality Control

Farmers have many demands competing for their time. Rice IPM education and communications must be of consistent high quality at all levels in order to engage their interest and maintain attendance in FFSs. Therefore, quality control measures should be a permanent, integral part of IPM implementation programs (34). Moreover, because farmers are constantly under commercial pressure to buy and use insecticides, IPM training must be adequately followed up in order for a program to have lasting impact. To help ensure quality, the Indonesian and Vietnamese community IPM programs send teams to observe and evaluate training and followup activities, and provide feedback and guidance on the spot. In-depth case studies help interpret impact data by studying the ecological, educational, and social processes at work (39).

The Policy Environment

Farmer training programs may be insufficient for IPM implementation unless they can be conducted within a policy framework that supports them and promotes IPM. Institutional support is a particularly significant issue for FFSs. In many countries, FFS implementation and impact are hampered by national institutions working under conflicting paradigms: traditional transfer-of-technology extension systems and crop protection services that warn farmers to spray their fields when wide-scale crop surveillance and pest forecasts indicate that pest populations may exceed fixed economic threshold levels (99).

Numerous policy options can support the implementation of IPM as a way to meet social, environmental, and crop protection goals (121). Eliminating pesticide subsidies is a powerful measure for reducing unnecessary pesticide use. Indonesia saved more than $100 million/yr by phasing out an 85% pesticide subsidy between 1986 and 1989, while rice yields went up and the price effect reduced average pesticide applications/season/paddy from over 4 to about 2.5. That rate is still far more pesticide use than is justified in rice, however, and it illustrates the fact that price policies alone will not rationalize pesticide use where continued overuse is perpetuated by factors such as pesticide advertising, pesticide sales by government agricultural staff, and fear of dropping calendar spray routines that were recommended for so long. Training that motivates farmers to withstand those pressures is essential for effecting real change. High-level political will must be complemented by grassroots activism prepared to demand its implementation (119).

It is particularly important to prevent crop protection and extension staff from being able to profit from pesticide marketing, officially or as informal salespeople on commission. In some countries, the ministry of agriculture sells pesticides to farmers. Pressures associated with that conflict of interest and the opportunity to top up inadequate incomes can motivate field officers to subvert IPM training (99, 151).

Women's Participation

Women play important roles in rice production (68, 76, 148), and initial steps were taken in the Philippines to involve women in IPM development and extension (36). Nevertheless, men have been the overwhelming majority of participants in Asian FFSs organized by national extension systems, due in part to a traditional focus on male landed farmers that excludes women from extension activities for production agriculture (71). Another barrier to women's participation is the day-long workload of child-minding and housekeeping tasks, in addition to farm labor. These responsibilities leave little time for attending IPM classes, let alone workshops or planning exercises that take one or more days, or require travel (14, 102). The FAO IPM Program is developing guidelines for strengthening women's participation and leadership in national IPM programs, including post-FFS activities (87).

New Rices, New Challenges

New kinds of rice promise to change the framework within which future IPM strategies will be developed. Some new rices may be more vulnerable than present cultivars are to pests or resistance breakdown. Farmers' skill and collaboration will be important for sustainable exploitation of their potential.

Hybrid Rice Hybrid vigor can raise rice yield potential by 15% to 20%. Hybrid cultivars are under development in many tropical countries, and a few have been released for commercial production. These cultivars inherit insect resistance from their parents, depending on whether the resistance genes are dominant or recessive (154). Hybrids may differ from inbred rices, however, in pest management-related characteristics as well as agronomic ones. Some Chinese hybrids appear to exhibit superior ability to compensate for stem borer and/or defoliator damage (98, 103; PE Kenmore & X Yu, personal communications).

Transgenic Rices Insect resistance has been among the top priorities of rice biotechnology (65). Extensive research is underway in dozens of public- and private-sector laboratories around the world. New tools for improved breeding and cultivar deployment include wide hybridization, DNA markers, genetic transformation, and DNA fingerprinting of pests (7).

The incorporation into rice of protein toxins from entomopathogenic bacteria, protein inhibitors of insect digestive enzymes, and certain lectins have been prime research targets (86, 147). Genes for protease inhibitors toxic to BPH have been inserted into rice (92). ‘‘Bt rice’’ containing delta-endotoxins from *Bacillus thuringiensis* (Bt) is farther along. Field trials began in China in 1997, and Bt rice will probably be available to farmers within a few years (MB Cohen, personal communication). Bt toxins confer resistance to stem borers and/or leaf-feeding caterpillars (7). As discussed above in Crop Loss Assessment Revisited, infestations of those pests normally do not justify control action at the level of the individual farmer. Scientists responsible for the development and deployment of Bt rices, however, maintain that Bt cultivars could prevent the loss of 5% to 10% of overall rice production as well as much unnecessary pesticide use (74).

Farmer education and cooperation will be key to deployment plans for genetically engineered rice, which must address ecological concerns and resistance management challenges in order to ensure safety and sustainability (74). In many Asian countries, insect resistance genes could spread into wild or weedy rices, perhaps enhancing their invasiveness (19). The possibility of indirect effects of Bt rice on natural enemies must also be explored. Moreover, the useful life span of Bt as a pest management tool both in rice cultivars and as a rice insecticide will be cut short unless special efforts are made to deploy Bt toxins in a way that prevents the development of resistance (20, 49).

New Plant Type Rice breeders hope to achieve a quantum increase in yield potential through modification of the present high-yielding semidwarf plant type. Creation and subsequent hybridization of a new plant type (NPT) with increased leaf area per unit ground area and more nitrogen stored in erect leaves (143) have the potential to increase yields by up to 25%. Lower tillering and thicker stems are important for the extra stem strength required to support increased panicle weight. Those characters may be associated, however, with the heavy stem borer damage observed in preliminary field trials, particularly damage by the striped stem borer *Chilo suppressalis* (Walker) (JE Sheehy, personal communication). Research to address this problem, including the incorporation of Bt genes into NPT cultivars, is under way (24).

Meeting Challenges with Improved Technology

Research Models Successful IPM requires research at all levels of the system. Breakthroughs made by research institutions and universities enabled early programs to be built on a sound scientific foundation. Since 1990, an IPM Network coordinated by the International Rice Research Institute (IRRI) and comprised of national IPM research programs in China, India, Indonesia, Lao PDR, Malaysia, the Philippines, Thailand, and Vietnam has contributed to the current understanding of rice-field ecology and interactions with nonrice habitats, farmers' pest control practices, and insecticide misuse (73).

In addition, a new model is emerging that offers an opportunity for farmer/research/extension collaboration in village-level research: post-FFS Action Research Facilities for experimentation by expert farmers. One such farmer group in the Indramayu province, Indonesia, developed a strategy for preventing infestations of the white stem borer *Scirpophaga innotata* (Walker), a locally severe problem long considered intractable. They then organized area-wide implementation by holding village, subdistrict, and district-level seminars (113). Scientists, including IPM Network collaborators, have begun facilitating other such farmer initiatives, which can benefit all concerned. Farmers have access to technical assistance with experimental design and the interpretation of results, while researchers can ensure that their work responds to farmers' priorities, produces results adapted to local circumstances, and enhances IPM implementation through farmers' heightened awareness and participation. All are empowered by acquiring constructive, nontraditional skills (82).

Priority Research Implementation must be an integral part of IPM research and development. Extension challenges are crucial subjects for IPM research. For instance, creative ways must be found to involve women more fully in rice IPM activities and to promote and support farmer-to-farmer training. In addition, extension programs must do a better job of educating farmers about, and instilling confidence in, the special properties of resistant cultivars in order to capture their potential pesticide use reduction benefits, including the potential benefits of genetically engineered rices (74, 101). Rice scientists' responsibilities should extend to collaboration with farmers and social scientists in order to better understand farmers' perceptions and motivations, draw on their insight and ingenuity, and be more responsive to their needs (56).

Scientists must ensure that new technology promotes, rather than endangers, the ecological balance in the paddy that protects rice from insect pest problems most of the time. Stable resistance and tolerance to insect pests continue to be valuable complements to natural controls. More work is needed to identify, and draw maximum benefit from, the strengths of hybrid rices. In addition, rice breeders should evaluate the impact of varietal characteristics on important natural enemies, with a view to combining pest resistance with characteristics that favor biological controls (10). Urgent research is required in order to deploy genetically engineered rices safely and sustainably, and to solve the NPT stem borer problem in a way that keeps the rice crop compatible with natural control-based IPM (19, 158). Too little is known about the effect of agrichemicals, including fungicides and herbicides, on paddy fauna. Attention is turning to ‘‘surrogate taxa’’ that could function as biodiversity indicators for monitoring trends and giving early warning of detrimental environmental change (137).

The conservation and enhancement of natural controls is a key research area. There remains much scope for designing rice systems, rotation crops, and landscapes that feed and shelter natural enemies and facilitate their access to newly planted paddies (137, 139). Exceptions to the general protection afforded by natural enemies of insect pests should also receive scrutiny. A better understanding of when and why pest outbreaks are triggered is necessary for creating ecologically sound control strategies, and for planning the improvement of present levels of natural control.

SERVING ALL THE FARMERS

About two million Asian rice farmers have graduated from FFSs. Helping the other 99% of Asian rice farmers to become IPM practitioners is a formidable task by any standard (60). The relative speed, impact, and cost-effectiveness of different extension and communication approaches are being analyzed and debated (57, 133, 115; LL Price, unpublished data). That discussion is muddied by the widespread misconception that FFSs and community IPM cover only IPM, whereas these programs aim to strengthen the initiative, the crop production knowledge, and the management skills farmers now need to increase their general productivity and develop their communities (12, 82, 117, 127, 152).

It falls to those responsible for IPM programs to implement the most effective combination of approaches and activities possible, in accordance with local objectives and resources. Communications media can be important in raising awareness and creating demand for IPM education, and can improve knowledge in some cases. SECs such as the Forty Days campaign are a relatively quick and cheap means of wide-scale achievement of specific objectives that lend themselves to simple messages. Interpersonal collaboration in educational activities with a broader scope, such as FFSs and support to farmer research, provides opportunities for participation and experiential learning, which are essential for empowering farmers as expert IPM practitioners and production management decision-makers (32). FFSs and Forty Days campaigns are being implemented simultaneously in some places. For example, Forty Days campaign materials in Vietnam urge farmers to contact the Ministry of Agriculture to request further

IPM training in FFSs, and the two extension approaches appear to be complementary.

The community IPM strategy is to create a dense network of FFS alumni groups that will spread IPM implementation horizontally, supported in large part by local resources (40). That strategy is meant to reach Asian rice farmers more quickly than is possible through direct training by the relatively small number of government extension or crop protection officers. Where successful, it would also lay the groundwork for extension by farmers. Farmers own and manage the agricultural extension service in Denmark (23). The Danish model may be useful for developing countries where people are ill served or unserved by government extension agencies.

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