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Working with Resource-Poor Farmers to Manage Plant Diseases

Farmers in developing countries have substantial difficulty in managing plant diseases (4). Poor farmers' understanding of disease processes is limited, and their disease management is often ineffective (21). This is, in part, because they cannot see the organisms that cause plant disease. They often lack access to information and technology that could help them raise healthy crops. Here we present and compare experiences in working with farmers to manage rice blast and potato late blight. In these cases, farmer groups learned about disease processes and management techniques, and tested promising crop varieties and breeding lines with the support of extension and research organizations.

The work was conducted using the "farmer field schools" (FFS) approach. This involves an intensive, hands-on training program following the extension methodology pioneered by the FAO's Intercountry Programme on Rice IPM in South and Southeast Asia (10,23). Since this program began in the early 1980s, millions of Asian rice farmers have been trained in Integrated Pest Management (IPM) through FFS. In a typical FFS, 25 farmers meet for a weekly half-day session with a trained facilitator over the full course of a cropping season. The farmers conduct a field experiment comparing IPM to conventional practice, and carry out various activities to learn about agroecological principles. Sessions take place in or near an experimental field. Each session has learning objectives and includes "group dynamics" to break the ice, hands-on activities such as development of an insect zoo, evaluation of field experiments, dramas, homework, and evaluation. The sessions require careful planning, and the facilitator's role is critical to promote an appropriate environment for research and learning. Substantial training is needed for a person accustomed to conventional extension to be an effective facilitator.

FFS often focus on management of insect pests in rice. Disease management presents different challenges than insect management, and different pathosystems may present unique problems (Table 1). In the case studies described here, field experiments were mostly aimed at testing individual disease management components. Some of these tests were conducted to demonstrate known phenomena, such as the increase of rice blast disease severity with increasing nitrogen input. Other experiments were considered farmer participatory research (FPR), which was oriented to develop or evaluate technological options such as the testing of elite breeding lines and genotype mixtures. The approach used is therefore designated FPR-FFS to distinguish it from FFS, which are more purely oriented to farmer training.

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Participatory Research in International Agriculture

The technology transfer model has been the dominant approach for agricultural innovation. A top-down approach can be effective in some cases, as exemplified by cereal breeding efforts aimed at relatively homogeneous production systems, and by the rapid uptake of chemically based technologies such as pesticides and fertilizers. But in many cases, technologies developed without farmer input are not suited to farmers' real or perceived needs and are not adopted (15). For knowledge-intensive technologies such as pest and disease management (here subsumed under the umbrella of IPM), farmers may not be able to utilize technologies without substantial access to information and training. To implement IPM effectively, farmers must adapt their management strategies and tactics to local pest complexes, cropping conditions, and operational constraints.

There is an increasing appreciation for the importance of involving farmers in processes aimed at improving agricultural practice among agricultural research, extension, and development organizations operating in developing countries. In 1982, Rhoades and Booth (16) argued that involving farmers in the research process increases the chance of success in the generation of appropriate agricultural technology. Since then, numerous publications have documented the advantages of farmer involvement in research, extension, and development efforts (15,17). Participatory approaches offer researchers a mechanism to ensure that their work is relevant to farmers' needs and conditions.

The collaboration of farmers and extensionists in participatory research may permit the collection of substantial datasets, enabling researchers to sample a broader range of environments than is possible with conventional on-station or even on-farm research. For farmers, collaboration with the formal research sector offers opportunities for continuing education on crop management, as well as early access to new technologies such as improved varieties. For extension organizations, involvement in participatory research offers access to innovative problem-solving approaches and other types of intellectual capital. Ortiz (13) indicates that extension workers can enrich their cognitive capital and enhance their decision making process by being involved in participatory research and training.

There are a number of well-developed models for farmer participatory research. One successful approach is the CIAL (for its Spanish acronym for "local agricultural research committee"), which was developed by researchers at the International Center for Tropical Agriculture in Cali, Colombia (3). Over 250 CIALs were active in the year 2000, mostly in Latin America and Africa (6). Through CIALs and other approaches, participatory plant breeding has been shown to be an effective way to select locally adapted genotypes

Table 1. Features of pest management cases, contrasting insects on rice, rice blast in southeast Asia, and potato late blight in the highland tropics

Problem	Role of pesticides in managementF	Role of varietal resistance	Availability and efficacy of other control measures	Level of farmer knowledge	Scientists' need for farmer participatory research (subjective)
Insects on rice (SE Asia)	Used but not needed (counterproductive)	In use	High (natural enemies)	Intermediate	Low?
Rice blast (SE Asia)	Used if pressure is high and resistance is low	In use; often not durable	Medium (agronomic practices)	Low	High (deployment of resistance)
Potato late blight (highland tropics)	Essential in many production systems, even when using resistance	In use; often not durable	Low (agronomic practices; but sanitation ineffective)	Low	High (epidemiology and deployment of resistance)

and to improve farmers' access to useful crop genetic diversity (9,18,19,24).

Improving farmers' ability to manage crop diseases requires both knowledge and capacity for innovation. Without understanding basic issues such as the pathogen as causal agent, sources of inoculum, and the concept of latent period, farmers are unable to grasp the basis for disease management strategies. To provide both information and technological options, we have embedded a substantial element of participatory research into a farmer training program. This is consistent with the analysis of Braun et al. (6), who suggest that the training elements of the FFS approach are complementary to the participatory research methods of the CIAL, and that it would be useful to combine elements of the two approaches to confront many problems in agricultural production.

Table 2. Organizations involved in farmer field schools focusing on participatory research and farmer training on plant disease management (FPR-FFS) in Vietnam

Organization	Role
Farmers' groups	Conduct field experiments; collect and analyze data; formulate and design new experiments for local conditions (some continued testing varieties for several seasons); share information with other farmers
The National Plant Protection Department (PPD)	Select farmers' groups; assist in developing and implementing new exercises for FFS and Training of Trainers (ToT); coordination
FAO's Intercountry Programme on Rice IPM	Assist national program; funds to support farmer groups and trainers; coordination and documentation
PPSD - IPM trainers	Assist in selecting farmers' groups and arrangements for field site; facilitate weekly training and research sessions
The National Institute for Plant Protection	Provide seed and technical support to facilitators
The International Rice Research Institute	Draft Field Guide (training curriculum); provide seed and support to national researchers

Managing Rice Blast in Central Vietnam

We describe here activities that were conducted in central Vietnam from 1994 to 1997 as a small component of Vietnam's national IPM program. The work involved collaboration among a group of national and international organizations, which are listed in Table 2. The collaboration was undertaken to help Vietnamese rice farmers improve their management of rice blast by linking the strong rice-breeding program at the International Rice Research Institute with Vietnam's strong rice extension program, which was supported by the FAO's Intercountry Program on Rice IPM (FAO IPM program).

The Vietnamese IPM program. The Vietnam IPM program was initiated in August 1992 through a collaboration between national and local agencies, and the FAO IPM program. As of October 1995, the IPM program had trained a total of 1,229 Vietnamese extension workers through a season-long Training of Trainers course. These trainers had conducted 5,000 FFS in the country, covering 3,095 of the country's 9,300 communes and providing direct training to 132,125 farmers.

One of the goals of the national IPM program was to strengthen the farmer groups that had undergone FFS training and to support them in follow-up activities that could further develop farmers' skills in pest and crop management and allow them to tackle additional challenges facing their communities. Groups of farmers that had participated in an FFS often declared themselves to be Farmer Clubs and were keen to undertake additional training and research efforts to pursue possible opportunities or to solve local problems.

Rice blast, caused by *Pyricularia grisea* (teleomorph: *Magnaporthe grisea*), was one of the constraints facing Vietnamese rice farmers. The disease was particularly damaging in central Vietnam, where weather conditions favor disease development because the rice crop is grown on a relatively thin strip of irrigated land between the sea and the hills. In spite of the availability of powerful components that could contribute to integrated management of the disease, farmers were often unable to manage the disease effectively.

Through discussions among staff of the FAO IPM program and the International Rice Research Institute (IRRI), it was proposed that farmer groups might undertake FFS activities in central Vietnam. Two communities were selected for initial pilot FPR-FFS for the 1994-95 cropping season. Members of these communities, Ha Lam and Duy Xuyen, had previously participated in FFS. They expressed interest in learning more about rice blast, about disease management, and about testing new rice varieties and breeding lines. Through discussions with members of the national and local extension services, it was agreed that the FPR-FFS would be facilitated by members of the local extension service of Danang Province, who would provide training support for weekly training and research activities.

FPR-FFS curriculum on rice disease management. A season-long training program on management of rice blast disease was developed, based on the format and methodology developed by the FAO IPM program. The curriculum was described in a field guide, which was written to serve as a guide for FFS facilitators. The first draft was based on the ideas of rice pathologists and extension specialists; this was then translated into Vietnamese and adapted and modified by the FFS facilitators and the participating farmers. The season-long FFS curriculum involved a set of field experiments supplemented by a series of learning activities. The field experiments included testing of promising varieties and breeding lines, testing of four different varietal mixtures, testing of a range of seed densities, and testing of different nitrogen treatments. The learning activities included discussions, observations, manual simulation exercises, and games.

Farmers learned about the nature of host resistance in several types of activities. Direct field observations were very convincing; resistance was striking, as many of the entries tested showed no disease. Manual simulation modeling exercises were also conducted to show how disease spreads and to illustrate the effects of quantitative resistance and of mixture effects (Fig. 1A). For the simulation exercises, the farmers drew a grid on a piece of poster paper. Each square of the grid was taken to represent a single plant. One or more beans were placed in random squares to represent the initial inoculum. For each infection cycle, additional beans were placed in the eight squares surrounding each "infected plant." Each infected plant was then marked (for instance, by placing a paper clip in each box with one or more beans). With the next "infection cycle," another eight beans were placed in the surrounding boxes for each infected plant, and the marker was removed. (Without the marking and unmarking of "plants" before and after "disease spread," the process becomes hopelessly confusing.)

Variants on this basic idea were used to illustrate various points about disease development. The potentially impressive cumulative effects of differing levels of quantitative resistance were shown by comparing the results of spreading 2, 4, 6, and 8 beans for each infected plant (Fig. 1A compares the results of spreading 4 versus 8 beans per plant per cycle). To show the potential benefits of using host genotype mixtures, different boxes were colored to represent different types of qualitative resistance. Different types of beans were used to represent different pathogen races, able to differentially attack different-colored host plants. The results of these simulations were impressive to researchers, extensionists, and farmers alike.

Farmers also learned about resistance and virulence through a card game (Fig. 1B). For each pair of players, one made and played a hand of host genotypes, while his or her opponent made and played a hand of pathogen genotypes. The former consisted of every combination possible of three resistance genes, illustrated as padlocks (red; blue; green; red and blue; red and green; blue and green; red, blue, and green), while the latter consisted of every possible combination of corresponding keys. As the players pitted a randomly drawn pathogen card against a randomly drawn plant card, they grappled with the gene-for-gene concept. By the end of the game, they realized that a system of three resistance genes could generate many resistant genotypes, but that the pathogen could match and overcome these. The farmers went beyond the intended scope of the exercise by pointing out that they would prefer to lock up the rooms of a house with different locks, so that a marauder with one key could not wipe them out. They made the explicit link to the desirability of using diverse rice varieties, to avoid the "boom-and-bust" cycles that they had already experienced with blast resistance.

Farmers learned about the environmental conditions favoring blast so they could evaluate the risk of a major epidemic. As farmers were already aware of environmental influences on disease development, this was mostly a case of pooling and reinforcing knowledge. A card game was used in which farmers drew a "hand" of conditions and then discussed the appropriate management decision to be taken.

FPR-FFS experiments for rice diseases. In its initial pilot version, the following treatments were tested in the FPR-FFS: approximately 50 rice genotypes (10 m^2 per entry), four genotype mixtures, and six nitrogen treatments. The designs and treatments varied somewhat over time and among the different communities. Each treatment was unreplicated, as replication was sought over communities (5). In retrospect, we think it would be worthwhile to decrease the number of treatments and include at least two replications per treatment, to help farmers in making sound judgments (this was done in the late blight case study presented below).

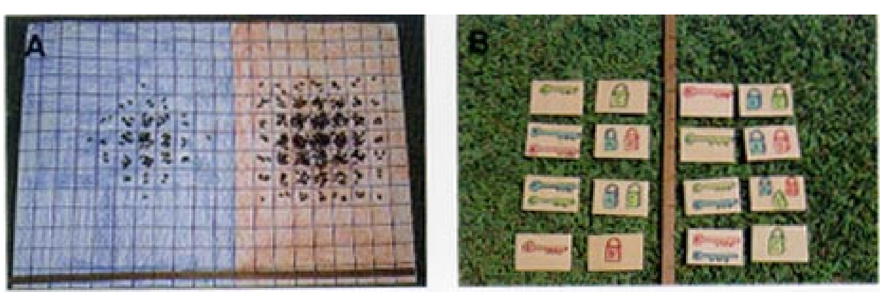

Fig. 1. Tools for teaching concepts of plant disease. A, Results of manual simulation exercise (bean modeling) used to illustrate disease progress for rice blast, comparing a susceptible host (left) with one carrying quantitative resistance (right). At left, eight beans were placed in boxes surrounding each "infected plant" (box with a bean) for each of three "infection cycles." At right, four beans were placed in the boxes surrounding each infected plant for each of three infection cycles. B, Card game used to illustrate the interaction of plant resistance and pathogen virulence. One player, representing the host plant, has a set of cards with all possible combinations of locks in three colors. His or her opponent has a set of cards with all possible combinations of keys in three colors. For each turn, each player plays a card at random. If the keys match the locks (if the pathogen could attack the host), the pathogen player takes the hand. If any lock is unmatched, the host player takes the hand. Left, card combinations in which the pathogen player wins; right, combinations in which the host player wins.

Participatory varietal selection. During discussions held with farmers prior to initiating the FFS focusing on rice disease, farmers indicated that they had only a single rice variety available to them for the blast-prone winter–spring season. This variety, IR17494, was an IRRI breeding line introduced as part of a brown-planthopper testing nursery in 1983. It was initially resistant to blast, but this resistance had eroded and had been ineffective since 1991. The province of Quang Nam Danang was not served by any rice breeder, and national breeding efforts focused on the larger Red River Delta to the north and the Mekong Delta to the south.

Farmers were enthusiastic about testing new varieties and breeding lines. They were also sensibly conservative about adopting them. Farmers wanted data from multiple sites and years before adopting a new variety, for the same reasons that researchers require the same. Although several of the entries showed promising resistance to blast and potentially higher yields and better quality than the farmers' standard variety, they were not hasty in replacing it.

The rice genotypes tested were chosen by the National Institute for Plant Protection and the International Rice Research Institute (IRRI). Vietnamese entries included genotypes from various national institutions. In the first season, 42 genotypes were tested in Ha Lam and 46 were tested in Duy Xuyen. The best-performing lines were tested in subsequent seasons, matching crop duration to the needs of the season. For the 1995 summer season, for which short-duration genotypes are desired, the farmers in Ha Lam retested the 10 best short-duration entries, while those in Duy Xuyen elected to plant 23 short-duration genotypes and 15 long-duration genotypes. In later seasons, the number of varieties tested in first-season FPR-FFS was reduced to 12, and a larger plot size (100 m^2) was used for each.

Farmers' groups and the National Institute for Plant Protection conducted parallel multiyear tests of the varieties introduced through the FFS, and two blast-resistant varieties were released. The variety MT6, developed by the Food Crops Research Institute, was selected by farmers in Ha Lam and was subsequently released. MT6 is now planted on 10,000 ha in Quang Nam Province, having replaced the susceptible IR17494 in the most blast-prone of the 41,000 ha of rice in that province. The genotype 88-65, developed by the Vietnam Agricultural Science Institute, was selected by the FFS participants and then released under the name Xi 21 in July of 1996. Xi 21 is grown on approximately 50,000 ha in north and central Vietnam for both winter–spring and summer crops.

Rice genotype mixtures. Host genetic diversity can be useful for suppressing plant disease epidemics (11,26). With the aim of identifying specific cultivar mixtures that would be effective and acceptable in central Vietnam, four genotype mixtures were tested in the FPR-FFS, each with three to four component genotypes. Two were constructed using IRRI breeding lines. A set of 10 elite IRRI rice lines was inoculated with a range of Philippine isolates of the rice blast pathogen, and lines showing differential interaction patterns (indicative of their possession of distinct resistance genes) were combined. Similarity of grain size was also taken into account, to ensure that the harvest could be milled together. The other two mixtures were designed from rice varieties available in Vietnam, based on their growth durations to ensure that the crop could be harvested together.

The results of the farmers' experiments were variable. For instance, in the first season, the mixtures performed substantially better than expected based on their component genotypes at Duy Xuyen, but the same mixtures performed substantially worse than expected at Ha Lam. In some experiments, the mixtures were not considered to be sufficiently uniform. Overall, farmers' interest in cultivar mixtures was not strong.

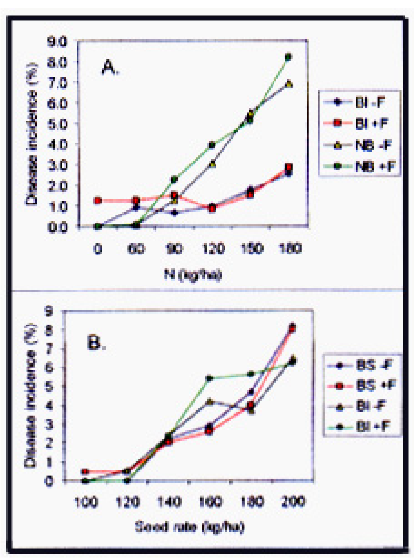

Fig. 2. Effect of nitrogen input, A, and seed rate, B, on rice blast severity. A, Data represent average values of unreplicated plots managed by farmers' groups of Ha Lam and Duy Xuyen villages in the 1994-95 season. B, Data were obtained from unreplicated plots by farmer field school group of Binh An Village, 1995. F = fungicide, BI = leaf blast, NB = neck blast, F = fungicide treatment.

Nitrogen. Nitrogen is well known to have strong effects both on rice blast and on rice yield (2). The intensification of rice production in northern Vietnam has had dramatic impacts on increasing pests and diseases, in particular rice blast and sheath blight (caused by *Rhizoctonia solani*) (20). While leaf nitrogen is a strong predictor of rice yield, levels of applied nitrogen are not well correlated with yield in surveys of farmers' fields because of the wide range of available nitrogen in rice soils (7). Thus, it would be valuable for farmers to be able to optimize nitrogen inputs on a very local level, taking into account effects on both yield and blast. Therefore, experiments were conducted using various levels of nitrogen, with and without fungicide treatment.

As expected, a clear relationship was observed between nitrogen input and blast incidence (Fig. 2A). Fungicide treatment was apparently not effective. Yield increased with nitrogen treatment up to a certain point, and then decreased. To ensure that farmers understood that different fields differ in their basal nitrogen levels, farmers experimented with a chlorophyll meter (SPAD meter; 22) and/or color tabs (25). The color of the leaves indicated the level of nitrogen taken up by the plants. With experience, farmers could learn to optimize their nitrogen level in such a way as to minimize disease and maximize yield.

Plant density. High plant densities can be associated with increased fungal disease (1). Farmers had relatively recently changed from transplanted rice to direct broadcast seeding, and seed rates in use were very high. For the first season of FPR-FFS, small areas with reduced plant density were included within the non-sprayed, standard nitrogen plots. The results of these initial experiments indicated that lower plant density resulted in a healthier crop, so the farmers decided to install a separate experiment on seed density.

To assess the effect of plant density on disease and yield, an experiment was conducted testing six planting densities. Disease was clearly affected by plant density as attained through varying seed rate (Fig. 2B). Seed rate also influenced brown spot, caused by *Bipolaris oryzae* (syn. Helminthosporium leaf spot). Again, fungicide was observed to be ineffective, presumably due to relatively low disease pressure. Yield was adversely affected by high seed rates, including the rates used by the participating farmers. Subsequent to their participation in the FPR-FFS, farmers indicated that they reduced their seed rate substantially and were saving on seed and fungicide costs as a result, while observing a generally healthier crop.

Fungicide. For each of the nitrogen treatments, half of the plot was sprayed and half was not sprayed with fungicide. At lower levels of disease pressure, fungicide effects were not impressive. At extremely high disease pressures, however, fungicide would be important to farmers growing susceptible varieties.

Development and expansion of the FPR-FFS for rice diseases. We recognized two phases in the development of the FPR-FFS. Phase I of the program (1994 to 1996) involved development, testing, and improvement of the curriculum based on

Fig. 3. Vietnamese farmers, A, conducting agroecosystem analysis, and B, preparing data posters after making field observations. Photos: R. Nelson, International Rice Research Institute (IRRI).

the experience of the farmers and trainers in central Vietnam. Phase II involved expansion of participation, further refinement of the curriculum, and selection of new resistant varieties. Workshops bringing together members of diverse organizations, including experienced facilitators, new trainers, and researchers, were very important for development and improvement of the curriculum, as well as for training of facilitators (12).

As noted above, two communities in central Vietnam participated in the first season (winter–spring crop of 1994-95), and four communities participated in the second (summer season of 1995). Photographs in Figures 3 and 4 show aspects of the FPR-FFS program. During the first season, a severe blast epidemic occurred in northern Vietnam, which created demand for participation in other parts of the country. Eighteen communities participated in FPR-FFS for rice diseases during the 1995-96 season, including two communities each from the provinces of TT Hue, Phu Yen, Ha Bac, Nam Ha, Thai Binh, Nghe An, and Bac Thai, as well as communities from Quang Nam Danang. In the summer of 1996, FPR-FFS focusing on rice diseases were initiated in southern Vietnam, where sheath blight is more of a problem than rice blast. By the year 2000, 87 FPR-FFS focusing on disease management had been conducted with the support of the FAO and the national IPM program, and another 97 had been conducted with the support of provincial governments. Thus, a total of at least 4,500 farmers have participated in the training program.

Conclusions: Rice blast management. Overall, farmers indicated that the FPR-FFS on disease management were most worthwhile. The rapid increase in the number of farmer groups participating in the activity and the increasing geographical range suggest that this was more than courtesy. First and foremost, the farmers were enthusiastic about having a greater understanding of plant disease, which had hitherto been dangerously mysterious.

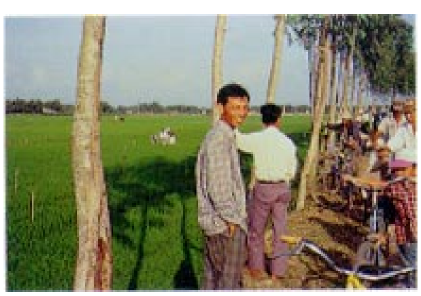

Fig. 4. Community members observing farmers' field trial in central Vietnam. The trial involved testing a set of breeding lines and varieties for resistance to blast and for general adaptation and acceptability, as well as testing of genotype mixtures, seeding rates, and nitrogen rates. Photo: R. Nelson, International Rice Research Institute (IRRI).

The farmers showed themselves to be excellent researchers and decision-makers. It became clear that rice blast could be managed, at least for the most part, through the use of resistance coupled with optimized nitrogen management and optimized seeding rate. Farmers interviewed indicated that, based on their observations through the FFS, they had reduced both seed and nitrogen inputs, and observed that their crops were healthier. The farmers readily adopted experimental methods and used them to improve their disease management strategies.

Blast pressure varied among sites and years. The performance of any one component of disease management depended on the environmental and plant conditions. Because it is dangerous to draw conclusions from any one experiment, farmers found it very useful to conduct exchange visits to each other's fields. They spent tremendous energy on their experiments, which were managed superbly, and took considerable pride in showing their fields to neighbors and to members of other farmer groups.

Deployment of rice varieties turned out to be more challenging than initially imagined. Although the local variety IR17494 had become very susceptible to blast, it was still so well adapted to the local environment that it was often difficult to outyield. Due to changes in staff at IRRI, the ongoing input of new and/or promising rice genotypes into the farmers' experiments was not aggressively pursued. Thus, although FPR-FFS for rice diseases have the potential to contribute to rice deployment and diversification, this promise has not yet been thoroughly fulfilled.

Managing Potato Late Blight in Northern Peru

CARE-CIP collaboration on potato pest and disease management. Peruvian government extension systems related to agricultural pest management were weak or nonexistent in the 1990s. Nongovernmental organizations were the most important source of agricultural technology and information. From 1994 to 1997, the International Potato Center (CIP) and the nongovernmental organization CARE-Peru collaborated in working with Andean farmers to improve IPM of the potato crop. During that period, IPM work focused on the most important insect pests of potato, the Andean potato weevil, *Premnotrypes* spp., and the potato tuber moths, *Symmetrischema tangolias* and *Phthorimaea operculella.* Starting in 1997, CARE and CIP extended the collaboration to include a major focus on potato late blight.

Late blight was considered to be one of the most important constraints to potato production in Peru, as well as in other developing countries. According to expert estimates, approximately 15% of the Peruvian potato crop is lost to late blight, although farmers spray fungicides for late blight an average of six times per season (T. Walker, CIP, *personal communication*). Every 20% increase in disease severity can result in a reduction of about 1 t/ha of yield, which is significant for farmers who harvest between 5 and 8 t/ha on average (14). Complete loss of the crop is not uncommon. Recent changes in the pathogen population had rendered the problem increasingly severe, and metalaxyl, a key fungicide, was no longer effective (W. G. Perez, J. S. Gamboa, Y. V. Falcon, M. Coca, R. M. Raymundo, and R. J. Nelson, *unpublished*).

To better understand the context of the pilot effort, CIP and CARE conducted a baseline survey in 1997-98 in the region where FPR-FFS were conducted. Ortiz et al. (14) analyzed farmers' perceptions and practices, and field-level damage in three provinces in the department of Cajamarca in northern Peru. This was intended to serve as a baseline study for the FPR-FFS, to allow analysis of the impact of the project, as well as to provide information needed for design of the FPR-FFS. The study revealed that while farmers derived income from a range of agricultural and other activities, potato was their most important crop. More than 90% of the 131 farmers surveyed considered late blight to be an important problem. The majority (67%) rated late blight as their most important problem, and 24% rated it their second most important problem. While the majority of farmers were well aware of the weather factors that favor disease development, few (9%) were aware that it is caused by a pathogen (14). The majority of the farmers (88%) were not able to distinguish late blight lesions from other foliar lesions. Although late blight was clearly important, it was not the only key pest cited by farmers; Andean potato weevil, frost, flea beetles (*Epitrix*), rots, potato tuber moth, and other pests were also considered destructive.

The majority of farmers interviewed (94.5% of 131 subsistence and semi-commercial small-holders) used fungicides as their principle method of late blight management, with an average of 6.6 sprays per season (14). Among the 887 spray applications made for late blight, the vast majority (>97%) involved dithiocarbamate-type fungicides (maneb group: maneb, mancozeb, propineb, metiram), which are classified by the U.S. Environmental Protection Agency as a probable human carcinogen (8). In 51.3% of the sprays, these contact fungicides were used alone, while in 47.3% of sprays, contact fungicides were used in combination with products that have systemic or translaminar effects. In 42% of cases, farmers applied mancozeb in combination with metalaxyl. Surveys of pathogen populations, as well as farmers' and researchers' observations, indicate that Peruvian populations of *Phytophthora infestans* had become resistant to metalaxyl (W. G. Perez and R. Nelson, *unpublished*). Farmers apply fungicides with backpack sprayers, mostly without any protection (R. Nelson, *unpublished observations*).

Most farmers were aware of the existence of late blight resistant potato varieties, but few had access to varieties with adequate levels of resistance. Farmers expressed strong interest in testing resistant varieties. Most of the farmers (85.5%) mentioned late blight resistance as a desirable characteristic of a potato variety. For three of the seven most commonly available varieties, late blight resistance was the most frequently mentioned reason for preferring the variety. Another important management tactic was to avoid planting in the rainy season, with the substantial disadvantage that in other seasons yields are constrained by the availability of water. Opinions varied regarding the effects of various agronomic practices on the disease.

At the beginning of this effort, CARE had been operating in the San Miguel area for several years and had established a wide range of activities related to community development. Through existing projects, a team of extension agents was providing agricultural extension services to many communities. CARE and CIP agreed to develop a pilot activity to adapt and evaluate the FFS as a way to give Andean communities improved access to knowledge and technology, and to encourage them to develop their own solutions to agricultural problems.

In contrast to the situation in Vietnam, the concept of FFS was new both to the extension personnel and to the farmers. CARE staff felt that the methodology was of interest and would perhaps have relevance as a general approach to community development. The farmers' willingness to participate was largely based on the fact that potatoes were important for them and they perceived that CARE could help them. The communities conducting FPR-FFS on potato agreed to meet fortnightly throughout the cropping season to conduct learning activities and field experiments. During the 1997-98 cropping season, four communities in San Miguel participated in the season-long FPR-FFS. Two facilitators were hired by CARE to support the FPR-FFS, with ad hoc financial support provided by CIP.

FPR-FFS curriculum for potato. The primary initial objectives of the FPR-FFS effort were to provide hands-on learning opportunities for groups of farmers interested in learning about late blight management; to give the farmers an opportunity to test and select resistant varieties; and to identify and integrate additional methods for disease, pest, and crop management. A basic field guide for facilitators was drafted to support the participatory training dimension of the FFS, and to guide the field experiments. As with the rice blast curriculum, the potato field guide describes group dynamics, learning-by-discovery activities, experiments, observations, and other tools to facilitate learning.

As a first step in the process of curriculum development, a series of workshops was held. The first was an Andean regional workshop conducted by CIP in Quito, Ecuador, to develop awareness about the FFS approach among research and extension organizations. National workshops were then held in Ecuador, Peru, and Bolivia, and FPR-FFS were initiated in all three countries through the interaction of the respective national programs and CIP staff based in each country. Curricula were developed independently in the three countries. In 1999, a project was funded by the International Fund for Agricultural Development, which supported the development of FPR-FFS for potato in six countries (Bangladesh, Bolivia, China, Ethiopia, Peru, and Uganda).

The focus here is on the work conducted in Peru. In drafting the first version of the Peruvian Field Guide, it was surprising to find how few of the activities could be easily transferred from rice blast to late blight. While the manual simulation games were extensively used for the rice blast work in Vietnam, these activities were poorly received in the Andes. One reason for this is that rice blast showed clearly focal epidemics, so that the simulation of disease spread was easily related to the process occurring in the field. Although potato late blight epidemics involve initial patchiness and spread in temperate areas, the disease often appears to begin with a uniform initial level of disease under Andean conditions, where year-round potato production and the presence of alternate hosts may lead to the presence of high levels of initial inoculum.

For the potato field guide, the use of mini-microscopes and moist chambers for the culture of lesions were important learning tools (Figs. 5 and 6). Farmers used small field microscopes to closely observe different types of lesions, and to see sporangia of *P. infestans* for the first time. Many farmers were excited to see the "little lemons" that cause so much destruction, and to realize that these tiny structures move through the air and also through the soil to attack the tubers. The curriculum involves a series of small experiments in which a farmer places plant tissue in a disposable plastic box or a plastic bag, together with moist tissue paper and a support (a few twigs) to keep the leaf, stem, or tuber out of direct contact with the paper. The moist chamber activity is used first as an aid to diagnosis. Farmers place different types of lesions in the chamber and watch what happens over several days, to learn the difference in the "life cycle" of a late blight lesion compared with a lesion incited by *Alternaria* or a spot caused by insect damage. Unlike other types of spots, late blight lesions rapidly overcome a potato leaf of a susceptible variety.

Farmers then use the moist chamber format to confirm that the sporangia washed from a sporulating late blight lesion do indeed incite new lesions on uninfected leaves, and that transmission can also occur when an infected leaf is incubated in the chamber with a healthy leaf. The transmission studies also show farmers that late blight lesions on leaves can lead to tuber blight. While most farmers participating in the FPR-FFS were familiar with late blight lesions on tubers, they were not aware that the problem is related to the phenomenon of leaf blight. This information allowed farmers to understand how high hilling can keep the tubers safer from the pathogen, and how removal of infected vines can decrease infection of tubers at harvest. The moist chamber can also be used to demonstrate different levels of resistance and the efficacy and nature of different types of fungicides.

While the Vietnamese rice farmers had already participated in FFS prior to undertaking a specialized program on rice disease, the FPR-FFS for Peruvian potato farmers was a unique opportunity to provide access to general information on crop and pest management. Thus, the curriculum was designed to cover important issues beyond late blight management, and its coverage has broadened steadily over its 4 years of evolution. Seed quality is a key issue in potato cultivation. In the FPR-

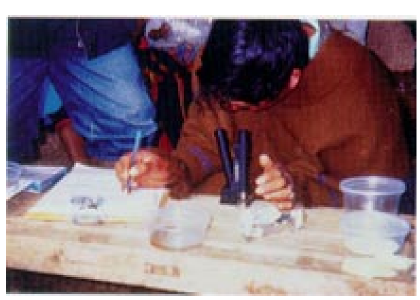

Fig. 5. Farmer drawing sporangia of *Phytophthora infestans* observed with a mini-microscope. Photo: R. Orrego, International Potato Center (CIP).

Fig. 6. Farmers setting up an experiment on the etiology of tuber blight, Peru. Photo: J. Llontop, International Potato Center (CIP).

FFS, farmers sort seed-lots into different types and discuss and then observe the effect of seed quality on the health of the crop. They learn how to maintain seed quality over seasons. In addition, increasing emphasis has been placed on management of key insect pests.

The field guide was initially designed to give session-by-session guidance for the FPR-FFS facilitators. After 2 years of curriculum development and modification with input from facilitators and farmers, the content became too broad to fit into a single season, and it became clear that it is important to tailor the content of the FPF-FFS to the specific needs of each participating community. Therefore, the curriculum was reorganized into sections, covering the different types of resources needed by a facilitator: general information, guidance for planning a season and a session, group dynamics, field experiments, learning activities, monitoring and evaluation, and technical information. Notebook and CD versions were developed to make this information more accessible to practicing or potential FPR-FFS facilitators. The responsibility for selecting among these resources to create a useful learning and research program was more explicitly placed on the facilitator.

FPR-FFS experiments for potato. Participatory experiments (on-farm trials conducted with active farmer involvement) are an important part of the FPR-FFS. For the first 2 years, participating communities tested a set of available genotypes, each with three levels of fungicide treatment. During the third cropping season, each FFS group conducted four experiments. One experiment compared three potato varieties with different levels of resistance, each managed with three different fungicide strategies. Another experiment involved a set of new clonal breeding lines, and a third involved entries derived from true potato seed. The final experiment compared "IPM" with "farmers' practice" treatments; this is the type of experiment typically conducted in a farmer field school. After the first 3 years, it was concluded that these experiments were overly complex, and simpler designs are being implemented for the fourth season of FPR-FFS.

In a "traditional" FFS, farmers conduct "agroecosystem analysis," quantitatively evaluating the factors that affect the crop, and capture their observations on a large poster. They typically draw the plant in the middle of the poster, illustrating the pests and noting their numbers per plant on one side, while noting the natural enemies on the other. The plant condition, as well as the weather and soil factors, are duly included and annotated in the drawing. This approach was adapted to allow the farmers to capture the observations made for each of their experiments. The process of collecting data and making posters allowed farmers to follow the progress of each experiment, and later to share their results with other groups at field days, and to participate in planning and decision-making processes between seasons.

Participatory varietal evaluation and participatory breeding. During a national workshop held in 1997, a set of promising potato varieties and breeding lines was selected by representatives of the national agricultural research institution, national universities, CARE, and other key stakeholders. For the first 2 years, one rather large and complex field experiment was conducted. This involved 12 to 14 varieties and breeding lines identified by breeders and others at CIP and in the national research program (INIA and universities). Each of the varieties was treated with three different levels of fungicide, and each treatment was replicated twice.

Fig. 7. Farmers enthusiastically observing the yield of a plant of variety Amarilis in the village of Lanchepampa in northern Peru. Photo: R. Orrego, International Potato Center (CIP).

Data were obtained for 16 varieties and advanced lines over the three field seasons from 1997 to 1999, with 20 to 90 evaluations of yield and AUDPC per entry overall. The formal analysis of these data will be presented elsewhere. The weather was generally conducive to late blight, and the susceptible genotypes were often killed by late blight irrespective of fungicide treatment. The yields of the moderately resistant genotypes varied according to disease intensity (which varied with local environment and fungicide treatment), and yields for most of the moderately resistant to susceptible entries were negatively correlated with mean disease levels. The resistant varieties performed well even at low fungicide levels. The overall mean yield of the most resistant entry was nine times higher than the overall mean yield of the most susceptible entry. Farmers who participated in the first year's FFS continued testing the best clones in their own fields.

The FPR-FFS have provided an opportunity for farmers to gain access to varieties previously little known in their areas, as well as to breeding lines not yet formally released. The most promising entry identified through the first year's FFS was Amarilis, a blight-resistant variety with which few local farmers were previously familiar (Fig. 7). After its success in the FPR-FFS, CARE provided credit to allow larger-scale production of Amarilis, and it has rapidly gained acceptance in the area. For example, 35% of families who participated in FFS had commercial plots with Amarilis after two cropping seasons of participation, compared with 10% of non-participant families. This 10% suggests that if an FFS group finds a good variety or clone, the material will be made available to other members of the community.

Starting in 1997, an agricultural cooperative and the national agricultural research institute each provided two clones. One clone per pair was considered to be good while the other was rejected due to late blight susceptibility, low yield, and tuber deformation. The two good clones were formally released by their respective nominating institutions, becoming nationally recognized and available after many years "on the shelf."

Based on the 1999 evaluations of eight FPR-FFS groups, one clone was consistently preferred. This clone, Chata Roja, was selected by the National Agrarian Research Institute (INIA) from a CIP cross made in 1984 (Fig. 8). In part based on the positive evaluation of the FPR-FFS, this clone was released by the Hermilio Valdizan National University (Huanuco, Peru) in 2000. Farmers' data from three FPR-FFS are shown in Figure 9.

In 1999-2000, a set of 50 newly identified breeding lines was tested among 19

FPR-FFS groups. Most breeding lines were tested in three to four communities, and each community tested approximately 10 new clones. At the end of the season, the farmers, facilitators, and researchers conducted a workshop to analyze the results of the testing of the new set of breeding lines. A subset of the clones was selected for continuing evaluation among the communities. Each community also tested a set of populations developed from true potato seed (TPS). As part of the FPR-FFS curriculum, farmers learned about TPS technology as an alternative approach to seed potato production.

Genotype by management by environment interactions. In the first and second years of FPR-FFS experiments, all of the entries were treated with three levels of fungicide protection. In the third season, a smaller experiment was conducted to demonstrate the interaction of three genotypes with different levels of resistance with three levels of fungicide treatment. For the farmers, the purpose of this experiment was to learn that fungicide spray decisions should be predicated both on the level of resistance of the crop and on the environmental conditions. Analysis of the 3-year dataset revealed that the effects of different resistance levels, fungicide spray intervals, and environments on disease were all highly significant, as were their two-way interactions. The three-way interaction was highly significant for disease severity ($P < 0.001$) but only marginally significant for yield ($P < 0.06$) (J. Heath, *personal communication*). The results are also being used to determine the extent to which a disease simulator is able to predict disease intensity.

Development and expansion of the potato FFS. In the first year (1997-98), four communities in the area of San Miguel, Cajamarca, participated in the FPR-FFS with the support of two full-time facilitators. The activity was funded in the second year (1998-99), allowing some expansion. Two of these four initial communities continued with a second season of activities, and an additional six communities in San Miguel initiated FPR-FFS. In addition, two FPR-FFS were established in Oxapampa, near a breeding site used by CIP's late blight project, to allow these communities to test a new set of breeding lines selected there. Photographs showing various activities conducted by the Peruvian FPR-FFS are shown in Figures 10 to 13.

Between the second and third FFS seasons, a group of facilitators participated in a 3-month Training of Trainers (ToT). The ToT was organized by the FAO's Global IPM Facility and funded by the FAO. Thirty-five extension specialists from Ecuador, Peru, and Bolivia participated in the ToT, which was held in Riobamba, Ecuador. During the 1999-2000 cropping season, 13 FPR-FFS were conducted in San Miguel, and an additional six FFS were carried out in other parts of the country by the facilitators trained in the Ecuador ToT. The facilitators put into practice experiences and ideas that they gained at the ToT. During 2000, a national IPM project was launched, financed by the Dutch government and administered by the FAO. This project is aimed at training a larger corps of facilitators and implementing FFS in potato, tomato, and cotton. It is hoped that the experiences gained from the CARE-CIP collaboration, as well as the field guide developed, will contribute to the success of the new project.

Conclusions: Management of potato late blight. Participating in FPR-FFS has allowed potato farmers to learn about plant disease processes, which in turn enabled them to make better management decisions about their crops. Farmers' knowledge and

Fig. 8. The late blight–resistant and red-skinned potato Chata Roja was highly appreciated by the eight farmer groups that tested it in 1998-99. Originally selected and recommended for farmer field school testing by the Hermilio Valdizán National University (Huanuco, Peru), Chata Roja was formally released by that university in 2000.

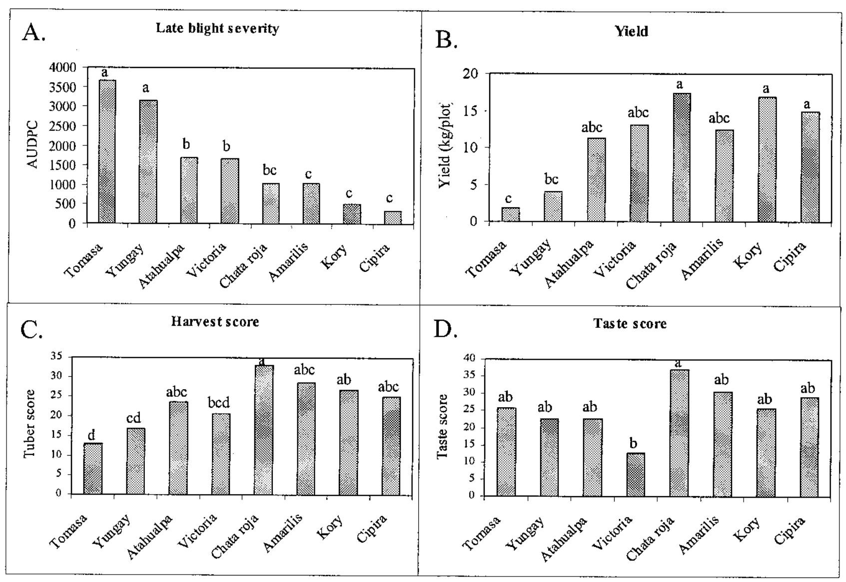

Fig. 9. Results of participatory varietal evaluation, 1999. Eight potato varieties were compared for: A, late blight severity; B, yield; C, farmer preference at harvest; and D, farmer preference at culinary evaluation. Letters indicate groups not significantly different by the Duncan-Waller test. AUDPC = area under the disease progress curve. "Tuber score" and "taste score" reflect the average numbers of "votes" accumulated by each entry in a farmer evaluation session. Farmers used maize kernels to indicate their preferences; each farmer placed three maize kernels in a bag corresponding to each entry considered superior, two kernels for each entry considered good, and one kernel for each entry considered inferior or unacceptable.

practices are currently being evaluated to assess to what extent new knowledge transforms into better management decisions. Preliminary results indicated that farmers have indeed improved their knowledge; significant differences were seen in the test scores of FFS participants, participants in other training methods, and farmers without training (Fig. 14). FFS participants had clearly gained knowledge about late blight biology and dissemination, control practices, availability of resistant genotypes, crop management practices, and general research principles (E. McCormick, G. Vasquez-Caicedo, J. Porto Carrero, C. Fonseca, and O. Ortiz *unpublished*).

Both farmers and researchers need a substantial amount of data in order to be able to judge adaptation and stability of performance across the diverse Andean environments. For this reason, the FPR-FFS are being considered as a network of farmer experimenters. By sharing data among communities, it is possible to make sound decisions and rapidly deploy promising new genotypes. For example, after an FFS conducted in Piura, Peru, farmers requested 600 kg of seed of a promising clone. This approach has stimulated the release of three varieties and the rapid deployment of these and other genotypes. In addition to receiving promising varieties, farmers also get early access to new breeding lines and have the opportunity to influence decisions about which materials will be released in the future. Work on FPR-FFS for potatoes in Peru is now part of a larger network of partnerships between research and extension organizations working in the Andes, Asia, and Africa.

General Conclusions

The work described here is part of a growing body of experience in participatory research and farmer training. In these cases, collaboration among farmer groups, extension organizations, and researchers on management of plant diseases has provided opportunities to all concerned. Our results support the emerging conviction that participatory approaches can facilitate changes in farmers' knowledge, attitudes, and practices by providing them with improved access to information and technology. In both the cases presented here, the FPR-FFS were successful in increasing farmers' knowledge and in identifying disease-resistant varieties and breeding lines meeting farmers' needs.

Partnerships among researchers, farmer groups, and community-development organizations providing training services can provide many of the requisites for rural development. Farmers need access to information and technology to improve their agricultural productivity, but infrastructure development and credit are also essential. In the Peruvian case presented here, CIP provided information and technology, while CARE provided training as well as credit and investment in infrastructure (construction of potato storage facilities, roads, and irrigation canals). Even so, price fluctuations sometimes proved defeating to potato growers. Appropriate policies affecting commodity and input prices are important for allowing farmers to improve productivity and sustainability.

Differences between extension systems, agroecosystems and pathosystems involved

Fig. 12. Farmer group in discussion session, Peru. Photo: J. Llontop, International Potato Center (CIP).

Fig. 13. Farmer's drawing of "selection of potatoes," reflecting enthusiasm for improved access to new potato genotypes.

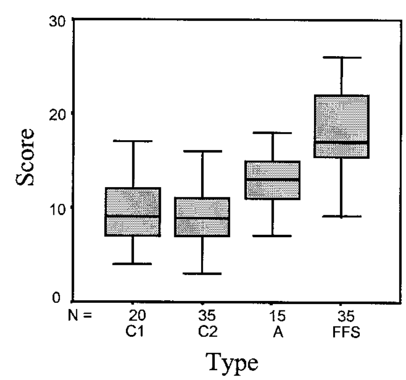

Fig. 14. Changes in farmers' knowledge as a result of their participation in Farmer Field Schools (FFS), San Miguel, Peru, 1999-2000 cropping season. Score is based on a questionnaire with 26 questions extracted from the FFS field guide. The black line within the square indicates the mean, the box includes 50% of observations, and the lines indicate the range of scores per category. Nonparametric Mann-Whitney U test, and the *t* test showed significant differences between average scores of different groups. C1 = Control group 1, consisting of nonparticipant farmers in communities with FFS. C2 = Control group 2, consisting of nonparticipant farmers from control communities (without FFS). A = Participants in the technical assistance project "Andino"; these farmers had received conventional extension training. FFS = farmers who have participated in Farmers' Field Schools. N = number of farmers involved in the test.

Fig. 10. Farmers' field experiment showing late blight–susceptible genotype in the foreground and resistant entry in the background, Peru. Photo: R. Orrego, International Potato Center (CIP).

Fig. 11. Peruvian farmer presenting results of field experiment to fellow participants. Photo: J. Llontop, International Potato Center (CIP).

Table 3. Comparison of the rice blast pathosystem in Vietnam and the potato late blight pathosystem in Peru

Characteristic	Rice blast, Vietnam	Potato late blight, Peru
Cropping system	Dominated by rice	Highly diverse
Accessibility of communities	Not difficult	Often difficult
Strength of national IPM program	Strong	Weak
Familiarity of farmer field schools (FFS) approach	High	None
Importance of disease	Damage usually ranges from low to moderate; occasionally high	Damage usually ranges from moderate to extreme; complete crop loss not uncommon
Known management components	Many. Plant density and nitrogen management useful	Fungicide, resistance, and avoidance of growing potato in the rainy season

had substantial implications for the content and efficiency of the FPR-FFS (Table 3). Rice cultivation is carried out in vast monocultures in Southeast Asia, while the Andean potato agroecosystem is highly complex. While a Vietnamese rice farmer may grow only rice, a Peruvian smallholder is likely to manage a number of crops as well as livestock. Crop rotation is an essential element of long-term pest management of Andean potato crops. The effectiveness of different management tactics differed for late blight and rice blast. The deployment and management of host plant resistance is extremely important for management of both diseases, but a number of agronomic decisions such as planting density and nutrient management have greater effect on rice blast than on potato late blight.

Differences in the epidemiology of the diseases affected the training techniques used. The rice blast curriculum made use of manual simulation modeling to illustrate focal disease development, as well as to show the value of varietal mixtures when using complementary qualitative resistances. However, the manual simulation exercises were not used for potato because late blight epidemics were not clearly focal in this region, and quantitative rather than qualitative resistance was deployed. The potato curriculum made extensive use of experiments conducted in moist chambers to aid in diagnostic capability and in understanding disease etiology.

Given the nature of plant disease, it could be argued that farmers' existing knowledge and experience is more useful than the relatively small amount of experimental data that they are likely to gather from experimentation in the course of an FPR-FFS. If little or no disease is encountered in their experimental plots, they will learn little about the technologies they are testing. Similarly, extremely high disease pressure may lead them to underestimate the potential utility of some management tactics. As one way of avoiding these problems, farmer groups testing disease-management technologies exchanged information and results. The networks of farmer communities allowed farmers to draw upon substantial datasets and to learn how technologies performed across conditions. The combination of participatory experiments with geographic information systems can allow researchers to understand disease progression under a range of different climatic conditions, and also farmers' responses to the disease.

Current and future efforts focus on the expansion of FFS to reach more farmers. These include training of farmer trainers, improvement of the scope and quality of the training curriculum, design of simple but useful experiments covering a range of issues in disease and crop management, use of multimedia computer technology to provide technical information to facilitators, and tighter linkage of breeding programs with FPR-FFS. Parallel development of sustainable local seed systems is also essential for long-term success.

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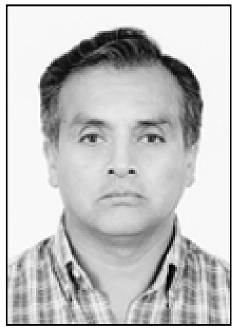
Rebecca Nelson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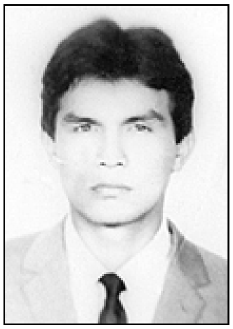
Oscar Oritz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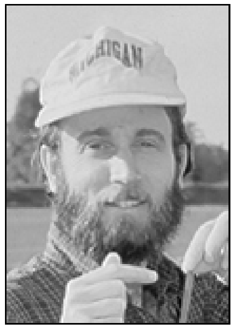

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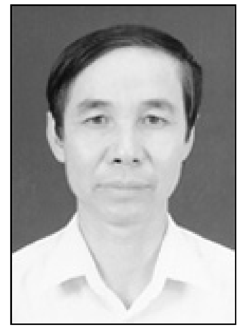
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