The Research Challenge for Integrated Pest Management in Developing Countries: A Perspective for Rice in Southeast Asia

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ABSTRACT This paper identifies some of the priority research that is needed to accelerate integrated pest management (IPM) toward more sustainable crop protection in developing countries. Perhaps the most important need is for research that measures how different IPM tactics contribute to long-term crop stability. Another is for research that critically examines the interactions of different pest control tactics. Researchers especially need to reevaluate the widely accepted view that host plant resistance and biological control are naturally complementary. Experimental data and population genetics models have challenged this view. Researchers also need to reevaluate the view that botanical pesticides, which many developing countries are promoting, are harmless to nontarget organisms. Examples show that some formulations of neem pesticides may negatively affect natural enemies and aquatic organisms. Crops engineered for pest resistance offer new opportunities in future IPM programs in developing countries, but their use opens questions about ecological and human health effects. IPM researchers should team up with ecologists, health specialists, economists, and others and critically evaluate effects of the engineered plants before farmers start planting them widely. Although basic research is essential to answer questions concerning exploitation of IPM tactics for best long-term results, research that builds on farmer practice also is an important need in developing countries.

KEY WORDS Research, integrated pest management, developing countries, ecological stability, host plant resistance, biological control, engineered crops, botanical pesticides

Since the 1960s agriculture in many areas of the developing world has transcended to a more modern, higher-yielding state. The Consultative Group on International Agricultural Research (CGIAR) has been a major catalyst behind the conversion. With voluntary pledges from more than 40 donors, CGIAR supports research and training at 18 centers aimed at improving production of specific crops

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and cropping systems (Plucknett 1993). The first two centers, the International Rice Research Institute (IRRI) in the Philippines and Centro Internacional de Mejoramiento de Maíz y Trigo in Mexico, focused on increasing yields of rice, *Oryza sativa* L., and wheat, *Triticum aestivum* L. Their main strategy was to breed new cultivars that produced high yields when irrigated and grown in dense plantings with high fertilizer input. By planting the new cultivars and using irrigation and fertilizers, farmers could increase crop yields by twofold or more (Jennings 1976). The resulting “Green Revolution” dramatically increased harvest of rice and wheat in Asia and Latin America and was a powerful incentive to increase yields of other primary food crops (Plucknett 1993).

CGIAR and other organizations similarly committed to developing countries have contributed significantly to the goal of achieving agricultural self-sufficiency. An example is the effort to increase rice production in Vietnam where 10 million farmers plant rice on 6.3 million ha, or 82% of the arable land (IRRI 1993b). Before the 1960s, Vietnam, like other countries of tropical Asia, produced only unimproved rice by traditional methods and yields were low. Since 1968, modern rice cultivars, new production technologies, improved irrigation systems, reforms in land tenure, and marketing have drastically changed this situation. Modern cultivars now cover 80% of Vietnam’s riceland, and production of rice has increased from 120 kg per capita in 1980 to 185 kg per capita in 1990 (IRRI 1993b, 1994). Since the mid-1970s, the average small-farm household’s share of income from rice harvests has increased from 20% to about 60%. Vietnam not only achieved self-sufficiency in rice production but also became a leading rice exporter. A rice importer until 1988, Vietnam became the world’s fourth largest exporter of that commodity in 1991.

Routine use of insecticides became a feature of farms planting high-yielding rice and other crops. Banks often required a full-season preventive insect control schedule as a condition to a crop loan. To meet this requirement, government pesticide subsidy programs gave farmers access to insecticides at very low costs (Repetto 1985). The developing countries imported most of the insecticides from developed countries, where many had been prohibited or heavily restricted. For example, nearly 40% of the insecticides used on Vietnamese rice are in the World Health Organization’s most hazardous Category I (Mai et al. 1993). Although developing countries may have pesticide laws, they usually lack resources necessary to enforce the procedures and to train farmers on correct pesticide use. Therefore, pesticide-related problems have increased with expansion of the high-yielding cropping systems. In irrigated rice in Malaysia, insecticide use has devastated fish populations cultured in the paddies for human food (Lim & Ong 1987). Few studies have quantified the impact of pesticides on human health in farming regions of developing countries. The study of Rola & Pingali (1993) suggests that use of Category I insecticides in the Philippines may increase human health problems and reduce farm productivity because of impaired farmer health. Furthermore, rice growers in southeast Asia that have been using insecticides have experienced serious problems with resurgence and secondary outbreaks of the brown planthopper, *Nilaparvata lugens* Stål. Brown planthopper eggs, in protected habitats inside the rice plants, are not killed by the insecticides, but their natural enemies are. Also, some insecticides stimulate the pest’s
fecundity (Chelliah & Heinrichs 1980, Chelliah et al. 1980). As rice farmers used large volumes of insecticides, crop damage from the planthoppers increased, resulting in heavy losses in many areas (Heinrichs & Mochida 1984, Kenmore et al. 1984).

Although chemical control strategies still reign in high-yielding cropping systems in developing countries, they are being increasingly challenged on economic, environmental, and health grounds. National and international organizations and farmer groups are reassessing the need for chemical control. Simultaneously, they are seeking sustainable systems of integrated pest management (IPM) that combine plant resistance with less expensive and nonchemical tactics, as several papers in this issue discuss. This paper identifies some of the priority research needed to accelerate IPM toward more sustainable crop protection in developing countries.

**Pest control tactics and ecological stability.** Although ecologists disagree among themselves about what ecological stability means and how to measure it, they generally perceive it as the ability of a community of organisms to withstand or recover from environmental perturbations (Pimm 1991). Ecosystems with higher stability show relatively low levels of fluctuations and recover relatively quickly from disruptions (May 1976).

MacArthur (1955) and Elton (1958) used empirical models and observations to show that increased complexity, characterized by more species and more ecological interaction, favored stability. The notion that complexity begets stability became an ecological paradigm (May 1976), and contributed to the argument that the relative simplicity of agricultural monocultures adds to their inherent instability. Empirical information suggesting that insect pests, pathogens, and nematodes tend to be more abundant in crop monocultures than in polycultures also helped to fuel the argument (Vandermeer 1990).

Consistently high ecological stability is rare even in the most stable ecosystems. However, high stability is not a prerequisite for achieving effective long-term crop protection if the pest population fluctuations do not exceed unacceptable levels (Risch et al. 1983). In modern rice production systems, chemical insecticides, which reduce natural enemy populations and also may stimulate the pest's fecundity, contribute more than other factors to extreme fluctuations in the brown planthopper (Kenmore et al. 1984, Heinrichs & Mochida 1984). Furthermore, Heinrichs (1992) and Gallagher et al. (1994) presented evidence that insecticides—by enlarging the pest population through resurgence and outbreaks—may accelerate brown planthopper adaptation to resistant cultivars. Therefore, “instability” in agroecosystems may relate to the way artificial inputs are used and the perturbations they cause more than it does to the inherent stability of the cropping system.

The assumption that rice and other high-yielding cropping systems are inherently unstable and therefore must be chemically protected against pests has stimulated prophylactic insecticide use. Mounting evidence shows that insecticide use is rarely necessary to protect yields of high-yielding rice in tropical Asia (e.g., Rola & Pingali 1993). However, policy makers and development agencies of developing countries will continue to promote insecticides on rice and other high-yielding crops until convinced that alternative control methods will ensure long-term crop productivity and stability.
Therefore, research that measures how different IPM tactics affect the relative stability of agroecosystems and what tactics may contribute most to long-term crop stability has more than academic relevance. Quantitative field studies of the short- and long-term ecological effects (e.g., perturbations by the tactics, recovery time following perturbations) of different tactics (alone and in combination) are needed to guide the selection of tactics that contribute most to long-term crop stability.

**Combining tactics to achieve durability.** IPM devotees commonly argue that IPM, by virtue of combining different control tactics, is less risky than crop protection, which uses a single tactic. By spreading the burden of crop protection across several tactics rather than just one tactic, IPM is supposed to reduce the risk of crop failure if one tactic fails. If unfavorable weather reduces the effectiveness of natural enemies, for example, the farmer would still benefit from those IPM methods (e.g., host plant resistance or crop rotation) not affected by weather. Further, evolutionary models predict that the less a given control method challenges a pest, the longer it will take the pest to adapt to the method (Gould 1988a, 1991). The idea of minimizing pest exposure to a control method is in fact a basic precept of IPM (Smith & van den Bosch 1967). By drawing from a wide range of pest controls and minimizing exposure to any one, IPM theoretically helps to reduce the rate at which pests adapt to and overcome the methods. However, few long-term field studies have been conducted to determine if a particular combination of IPM tactics introduces less (or more) risk to crop production or if the tactics are compatible (or antagonistic). Studies of the combined effects of host plant resistance and biological control are especially needed considering the attention that these tactics are receiving in developing countries. International research centers such as IRRI (1993a) and the International Institute of Tropical Agriculture in Nigeria (Yaninek & Schulthess 1993) have major programs in host plant resistance and biological control.

A widely accepted view has been that host plant resistance and biological control are naturally complementary. However, Hare (1992), summarizing data from studies on a range of natural enemy species, refuted the argument that the two tactics are always compatible. In some cases, resistant plants favored natural enemies, but in others they had a negative impact. Even if natural enemies are protected from pesticides and cropping practices are favorable for their increase, they will not do satisfactorily on inhospitable plants.

Clearly, efforts to exploit plant resistance and biological control should evolve together. The ideal form of plant resistance may be when resistant cultivars suppress the pests and simultaneously benefit natural enemies. A high level of pest resistance may not be necessary because the partial resistance would be potentiated by actions of natural enemies. Furthermore, partial resistance would put less selection pressure on the pests and theoretically would be useful in slowing the rate at which pests adapted to and overwhelmed the resistance. However, population genetics models of Gould et al. (1991) and Johnson & Gould (1992) suggest that some natural enemies may accelerate the rate at which insect pests adapt to resistant plants. Much more ecological field research is needed to test these models and to map out optimal
strategies for combining plant resistance, biological control, and other tactics so as to achieve maximum durability.

Botanical pesticides. Many developing countries are promoting botanical pesticides as alternatives to synthetic organic insecticides. Long used by farmers of these countries, botanicals are naturally occurring and renewable and, to some, the ideal pest control agents. However, information is showing that botanical pesticides may not be as harmless to nontarget organisms as generally thought. In their review of the effects of neem, *Azadirachta indica* A. Juss., products on nontarget organisms, Lim & Bottrell (1994) documented effects ranging from harmless to adverse. Adverse effects included reduced emergence of adult parasitoids from neem-treated parasitized cocoons, e.g., braconid wasp *Cotesia plutellae* Kurdj. (Loke et al. 1990); direct mortality, e.g., green mirid bug *Cyrtothirus lividipennis* Reuter (Saxena et al. 1984); repellency, e.g., coccinellid beetle *Delphastus pusillus* Le Conte (Hoelmer et al. 1990); and reduced fecundity, e.g., bethylid wasp *Goniozus triangulifer* Kieffer (Lamb & Saxena 1988). The coccinellid predator *D. pusillus* avoided the eggs of its treated prey, whitefly *Bemisia tabaci* (Gennadius) for 1 d, then resumed feeding the next day (Hoelmer et al. 1990). Neem had a longer-lasting impact on other natural enemies. For example, the emergence and fecundity of adults of the parasitoid *G. triangulifer* were lowered when its pupae were treated with neem (Lamb & Saxena 1988).

Neem also is toxic to various aquatic organisms. Because of the toxicity to aquatic invertebrates, the label of the neem product Margosan-O, sold in the United States, specifies “Do not apply directly to water or wetlands” (Larson 1987). Yet many developing countries in Asia are promoting neem products in irrigated rice.

The rapid disappearance of naturally forested land and the abandonment of traditional pest control practices in the tropics add to the importance of examining the potential of plants for pest control agents. However, efforts to exploit plants in pest control should put as much emphasis on studying possible side effects as on studying potential benefits. Just because farmers in developing countries have long used botanical pesticides does not guarantee that they are more safe than synthetic pesticides—some of the most toxic substances occur in plants.

Engineered crops. Genetically engineered crop plants have been developed for some 30 plant species (Khush & Toenniessen 1992). Genetic engineers have inserted genes for a variety of desirable agronomic traits into these crops, and crop engineering is presently in the global limelight of agricultural science.

Sharing this light is a dispute between those promoting crop engineering technology and those concerned about the risks it creates (Kareiva 1993). On one side are those who slough off concerns about risks. On the other side are those concerned that transgenic crop plants may become “exotic-like” weeds of agriculture; invade and cause ecological disruptions in natural habitats like exotic natural species do; hybridize with wild relatives and therefore modify the wild relatives’ natural gene pool; or cause human health problems. Also, some are concerned that transgenic crops developed for pest resistance will remain useful for only a short period because high selection pressure will force pests to adapt quickly and therefore overcome the resistance (Gould 1988b).
As Kareiva (1993) pointed out, horror stories about exotic species are probably not a fair analogy for single-gene modifications in crops domesticated for long periods. However, the classical plant breeding record itself is not completely free of undesirable effects. For example, to solve the problem of weedy wild rice (uncultivated species of *Oryza*) that resembles and competes with cultivated rice *O. sativa*, breeders in India bred rice plants with reddish-purple coloration. This technique allowed the weeders to pull out the green *Oryza* weeds (Dave 1943). The approach worked well until the wild rice plants also developed a reddish-purple color, presumably by exchanging the color-enhancing gene with cultivated rice through hybridization (Gould 1991).

There is no evidence that engineered crop plants with resistance offer any greater durability than crop plants with resistance derived by traditional breeding. Gould et al. (1992) have already shown that laboratory populations of the tobacco budworm, *Heliothis virescens* (F.), can develop cross resistance to different toxins of *Bacillus thuringiensis* Berliner, similarly to the way they have developed cross resistance to chemical insecticides. Many public research organizations and companies are now engineering crop plants with genes of *B. thuringiensis* that encode insecticidal toxins (Tabaschnik 1994). Some of these crops are likely to be planted widely in developing countries.

The United States and other developed countries have regulatory agencies, environmental groups, and sophisticated research programs to guard against ill-fated use of engineered organisms. Developing countries usually lack such safeguards. A World Bank (1993) publication appraised developing countries of potential problems with engineered rice with guidelines on how to reduce the risks. Some developing countries have independently developed their own guidelines for engineered crops. However, it is questionable if resources will become available to allow these countries to follow the guidelines. Few developing countries have had resources to follow even the least complicated guidelines for ensuring pesticide safety.

Crops engineered for pest resistance offer many opportunities in future IPM programs in developing countries. However, researchers should critically weigh their benefits against their potential undesirable side effects. The goal should not be to see how little time is required to develop new transgenic plants with pest resistance, but to prolong the plants’ usefulness in durable deployment systems without provoking undesirable side effects. IPM researchers should team up with ecologists, health specialists, economists, and others and critically evaluate effects of engineered plants before farmers start planting them widely.

**Farmer participatory research.** Although basic research is essential to answer questions concerning exploitation of pest control for best long-term results, research that builds on farmer practice (Fujisaka 1991) is equally important. Some researchers may view farmers’ indigenous systems in developing countries as irrelevant; others have discovered that success in adoption of new technologies requires an understanding of farmer knowledge and practice (Bramer 1980).

Escalada & Heong (1993) provided a good example of how farmers’ perceptions affect pest control operations and how they can be changed by simple farmer participatory research (FPR) methods. By participating in an experiment on their fields, farmers discover the significance of a concept related
to IPM. For example, a large portion of Philippine rice farmers use insecticides on young rice (1-40 d old) to control various leaf-feeding insects. They perceive that they will suffer heavy losses without the insecticides. However, considerable field research shows that insecticides are not necessary to protect yields and may trigger outbreaks of brown planthopper. Escalada & Heong (1993) therefore organized a FPR experiment in which each participating farmer withheld insecticides on a portion of the rice field for the first 30-40 d but treated the rest of the field normally. At harvest, farmers obtained yields from both portions and then discussed results with other farmers in a workshop. This method was quite effective in getting farmers to stop early-season treatments.

**Concluding remarks.** Research is obviously needed to develop and evaluate IPM concepts and practices in developing countries, but it is useless without companion efforts in extension and training. Experience with IPM in rice in southeast Asia shows the importance of training. Even farmers with low levels of formal education have responded favorably to the training, quickly adopted IPM, eliminated unnecessary insecticide use, and in turn trained other farmers to do the same (Matteson et al. 1994). Future efforts in IPM research should evolve in parallel with the training efforts. The FPR approach especially appears to complement the training programs and should reduce costs of introducing IPM in developing countries.

**References Cited**


