IPM Research Brief No. 4
The Systemwide Program on Integrated Pest Management

spIPM
for improved livelihoods

Biological Alternatives
to Harmful Chemical Pesticides

About the SP-IPM

When delegates to the Earth Summit met in Rio de Janeiro in 1992, they recognized a looming crisis in international development. Attempts to raise living standards through conventional development approaches were not only having a woefully limited impact on poverty and other indicators of underdevelopment, they were also 'costing the earth'. In effect, inappropriate development strategies were destroying the planet's ecological life support systems.

In the field of agriculture, undue reliance on pesticides and fertilizers to raise production was undermining the sustainability of that production. In the Agenda 21 action plan that emerged from the Summit, integrated pest management (IPM) was explicitly recognized as a key part of the solution to this problem. It would allow more food to be produced with less negative impact on agricultural and natural ecosystems. In 1996, as part of its response to Agenda 21, the Consultative Group on International Agricultural Research (CGIAR) launched its Systemwide Program on Integrated Pest Management (SP-IPM).

The SP-IPM is a global partnership whose task is to draw together the IPM efforts of the international agricultural research centers and their partners, and to focus these efforts more clearly on the needs of poor farmers in developing countries. The program tackles those areas where research promises solutions to pressing problems of sustainable agriculture but where impact has so far been limited. The SP-IPM expects to achieve rapid progress by alleviating constraints such as fragmentation of research and development (R&D) efforts and weak links between researchers and farmers. It is already breaking down barriers to information exchange, filling research gaps where necessary, and developing effective models of partnerships among researchers, extensionists, and farmers. Specifically, the SP-IPM promotes:

- Inter-institutional partnerships for increased effectiveness of IPM research
- Holistic and ecological approaches and methodologies for IPM technology development
- Effective communication among stakeholders for informed IPM decision-making
- Farmer uptake of IPM technologies for larger, healthier harvests
- Public awareness of IPM and its impact on sustainable agriculture.

The program's stakeholder groups are as follows: international research institutions that include IPM as a major part of their agenda; specialized agencies and networks promoting and supporting IPM; non-governmental organizations (NGOs) and farmer support groups; and the plant protection industry. The R&D organizations and farmers who are our principal clients benefit from the program through access to technical resources and expertise, information, advice, collaborative field activities, and capacity-building activities. All these services aid their efforts to manage pests, achieve greater food security, and raise their incomes within a healthier environment.

Core donor partners are the Governments of Norway, Switzerland, and Italy. Donors supporting special projects have included funding agencies in Australia, Denmark, New Zealand, the United Kingdom, and the United States, as well as the Global IPM Facility and the World Bank (through the CGIAR).

For more information write to:
SP-IPM Secretariat
International Institute of Tropical Agriculture
08 BP 0932 Tri Postal, Cotonou, Republic of Benin
E-mail: ipm-center@cgiar.org   Website: www.spipm.cgiar.org

About this Brief

The IPM Research Brief Series is part of the SP-IPM's strategy for promoting information exchange among stakeholders. Its purpose is to build public awareness and understanding of the benefits of integrated pest management (IPM) and to encourage the full integration of this approach into mainstream agriculture.

The briefs are primarily intended for agricultural research managers, policy makers and the development partners with whom governments plan IPM inputs into agricultural and rural development activities. The briefs analyze the biological and ecological bases of IPM-related food security issues across different agroecosystems and regions. They also synthesize research results and advise on opportunities for scaling up the benefits achieved in pilot studies.

This brief addresses one of the fundamental issues in agriculture and development: the use of chemical pesticides. While the benefits to crop production are clear, the costs – to health and environment – are often hidden. In particular, the group of chemicals known as persistent organic pollutants (POPs), which includes pesticides such as DDT, have unacceptable negative impacts. Many biological alternatives exist and can be useful to farmers within an integrated pest management approach. This brief provides an overview of biological alternatives and examines some examples of their current use. It also looks at ways to promote the availability of these options for farmers in developing countries.

This brief was prepared by the SP-IPM Secretariat in collaboration with Green Ink Publishing Services Ltd (UK). It is based on discussions and outputs from a workshop held by the United Nations Industrial Development Organization (UNIDO) and the SP-IPM in Benin in 2004, entitled 'The search for alternatives to banned/restricted POPs in Africa'. The brief expands the focus beyond Africa to developing countries generally. We would also like to acknowledge the help of scientists and development workers from the International Institute of Tropical Agriculture (IITA), Centro Internacional de Agricultura Tropical (CIAT), International Centre of Insect Physiology and Ecology (ICIPE), Pesticide Action Network UK (PAN-UK) and Valent BioSciences Corporation.

Correct citation:
SP-IPM (2006). Biological Alternatives to Harmful Chemical Pesticides. IPM Research Brief No. 4. SP-IPM Secretariat, International Institute of Tropical Agriculture (IITA), Cotonou, Benin.

IPM Research Brief No. 4

Biological Alternatives to Harmful Chemical Pesticides

Contents

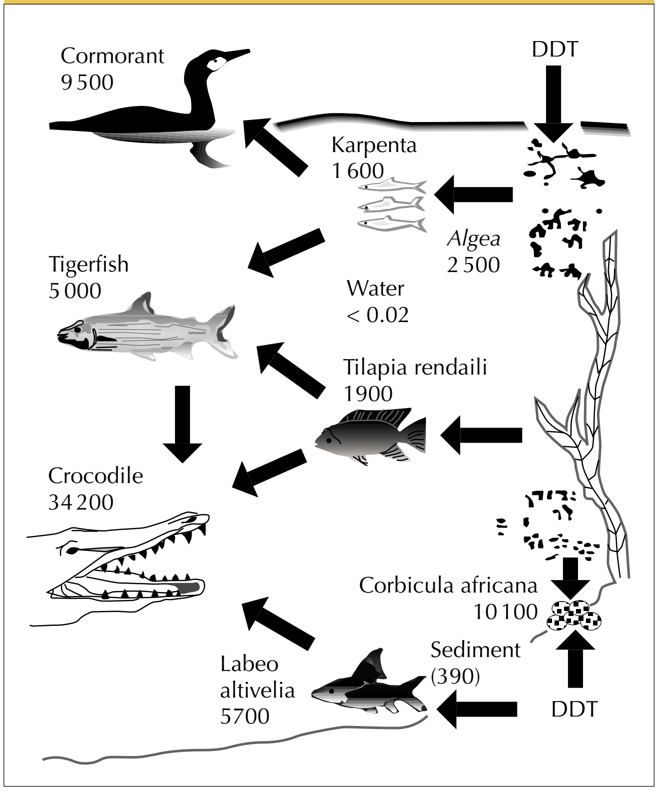
A Chemical Legacy

Insects and other species that damage crops or that transmit diseases to people or animals – and are therefore pests – need to be controlled as far as possible. For many hundreds of years, farmers managed crop pests in a variety of ways that were harmless to the environment. But as the human population soared in the twentieth century, and food production became much larger scale, new approaches to pest control were sought – and found. New synthetic chemicals promised a quick and easy way to manage pests, and the agrochemicals industry was born. Chemicals also became mainstream in other areas of life, for example in public health to fight mosquitoes and other disease-carrying insects (vectors); in construction to control termites; and in industry as lubricants, paints and adhesives.

As with many other new technologies, the long-term consequences went largely unconsidered in view of the short-term benefits. The impacts of chemical pesticides were initially positive, and people benefited enormously. But over time, it became clear that some of these pesticides had serious negative impacts, on human health and the environment.

The most offensive of these are called persistent organic pollutants or POPs. Among the POPs are eight organochlorine pesticides – aldrin, camphechlor (toxaphene), chlordane, DDT, dieldrin, endrin, heptachlor and mirex – which have been used over recent decades in agriculture, industry, public health and forestry. Some continue to be used today.

Figure 1. Mean levels of DDT residues (ppb in fat) in the Lake Kariba ecosystem, showing accumulation through the food chain



Reproduced from Berg et al. (1992), with permission from Ambio

POPs take a long time – sometimes decades – to break down into harmless substances. During that time they accumulate through the food chain, concentrating in the fatty tissue of the top predators, with highly toxic effects (Figure 1). In humans, these chemicals have been linked with damage to the nervous, reproductive and immune systems, to the liver and to cancer. Humans appear to be particularly sensitive to these chemicals during fetal development. POPs are also linked to reproductive failure, deformities and other malfunctions in fish and wildlife. To make matters worse, there is evidence of long-range transport of these chemicals to distant parts of the world, where they have never been used. Particles are carried by the wind, and tend to deposit in cooler places, such as polar regions and mountainous areas. POPs are thus having widespread, long-term health and ecological consequences that were never anticipated or intended.

DDT is probably the best known POP. Developed in the 1930s, DDT was used extensively in Europe and North America during the 1940s and 1950s, and was responsible for the eradication of malaria from these regions. It was also used as an agricultural insecticide. But by the 1950s resistance had developed in some insect populations, and doses had to be increased to be effective. Also, evidence began to emerge of the chemical's persistence and accumulation in the food chain, and its toxic effects. In 1962, Rachel Carson's book *Silent Spring* brought the dangers of DDT to public attention, and it became a focus for environmental activists. During the 1970s and 1980s, most developed countries banned the use of DDT. However, today DDT is still used in many tropical countries in the ongoing fight against malaria.

The current situation with DDT illustrates the inequality of chemical pollution. The industrialized countries, where these chemicals were developed, had the resources to find relatively benign alternatives when their harmful effects came to light. Poorer countries, in contrast, have come to depend on these chemicals and in many cases lack the resources needed to find replacements. This is compounded by the complex situations in which the chemicals are often used, for example the diverse agricultural systems of Africa. Finding replacements in these situations is usually far from straightforward.

However, biological alternatives to harmful agrochemicals do exist. Many have been successfully tested in field trials and some are commercially available. But for various reasons, which are explored below, they are proving slow to reach the majority of farmers, and particularly small-scale farmers in developing countries. Similarly, there are safer ways to manage insects that carry disease. A global effort is needed to contain the damage from the chemical legacy of the last century, and to find and put into use ecologically sound, technically effective, economically feasible and culturally acceptable alternatives.

Children playing with discarded pesticide cans

The Real Dangers of POPs

It is impossible to produce exact data on the number of people affected by POPs and other dangerous chemicals. However, a joint report by the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO) and the United Nations Environment Programme (UNEP) released in 2004 agreed with the broad estimate of between one million and five million cases of pesticide poisoning each year, resulting in several thousands of fatalities. The report pointed to the inequality of poisonings, with most occurring in developing countries. According to the report, "Most of the poisonings take place in rural areas of developing countries, where safeguards typically are inadequate or lacking altogether. Although developing countries use 25% of the world's production of pesticides, they experience 99% of the deaths due to pesticide poisoning."

The report also drew attention to the vulnerability of infants and children, who may be at greater risk than adults because they are more susceptible to the effects of pollutants, or because they are exposed more. In Egypt, for example, over 1 million children help with cotton pest management, exposing them to pesticides. Over 13,000 children in West Africa are involved with applying pesticides in cocoa production. And in Iran, pesticides were found to be the leading cause of deaths from poisonings in children.

The World's Response

The United Nations Conference on Environment and Development in Rio de Janeiro in 1992, also known as the Earth Summit, paved the way for such an effort. The resulting action plan, Agenda 21, recognized the POPs problem as a priority. In a follow-up to this, UNEP brought together concerned groups to discuss ways to tackle POPs and other dangerous chemicals. The result was the Stockholm Convention, which came into force on 17 May 2004, and targets in the first instance the 12 most dangerous POPs: eight pesticides, plus two unintentional by-products of industrial and combustion processes (dioxins and furans) and two industrial chemicals (polychlorinated biphenyls (PCBs) and hexachlorobenzene). Parties to the treaty – numbering 119 governments by March 2006, with 32 further signatories yet to ratify – agree to measures to phase out the production and use of these POPs, and are required to develop national implementation plans for meeting the treaty's targets.

The Convention has five aims:

1. Eliminate dangerous POPs, starting with the 12 worst
2. Support the transition to safer alternatives
3. Target additional POPs for action
4. Clean up old stockpiles and equipment containing POPs
5. Work in a global partnership for a POPs-free future.

The Convention recognizes the inequality of the POPs problem, and calls for international aid to help developing countries deal with POPs. One response to this is the Africa Stockpiles Programme, which was set up to deal with the estimated 50,000 tonnes of obsolete pesticides stockpiled across Africa. In its early stages, the Programme is beginning clean-up work in seven African countries – Ethiopia, Mali, Morocco, Nigeria, South Africa, Tanzania and Tunisia – with nine more targeted for the second phase. The entire operation will cost an estimated US$250 million. Donors to date include bilateral and multilateral funding bodies, and also the chemical industry through CropLife International, a global network of commercial agriculture companies.

The Stockholm Convention and the Africa Stockpiles Programme largely focus on destroying existing supplies of POPs and stopping future production. But ridding the world of dangerous POPs is only half of the story. Alternatives are needed to take their place, a need that intensifies as the push to destroy stockpiled chemicals gains momentum. In the absence of available alternatives, and so long as the chemicals exist, farmers and others who have come to rely on them may out of necessity revert to using them. For example, until an effective alternative to DDT is easily and cheaply available, countries struggling with the huge burden of malaria may have no option but to continue using this dangerous chemical. Indeed, there has recently been increasing demand for DDT in African countries, re-

A Partnership Against POPs

The United Nations Industrial Development Organization (UNIDO), a UN agency with a mandate to help developing countries achieve sustainable industrial development, has been involved in reducing emissions of POPs since the 1980s. Its experience and comparative advantage in this area was recognized by the Global Environment Facility (GEF) when it was named as Executing Agency with Expanded Opportunities, a status that allows UNIDO direct access to GEF material resources to help countries fulfill their obligations under the Convention. This includes resources for so-called Enabling Activities that will lead to the development of National Implementation Plans for managing and eliminating POPs.

The System-wide Program on Integrated Pest Management (SP-IPM) is a global partnership program that was established in 1996 as part of the Consultative Group on International Agricultural Research's (CGIAR's) response to the Agenda 21 action plan of the 1992 Earth Summit. Agenda 21 identified integrated pest management (IPM) as being crucial to solving the twin problems of environmental degradation and poverty in developing countries. The SP-IPM aims to help all its partners (a full list appears on the inside front cover of this Brief) raise the quality and usefulness of IPM research and outreach to the dual advantage of people and the environment.

flected in the rising number of requests for exemption from the DDT ban: by 2006, some 19 African countries had requested exemption.

Certain barriers have been identified that are hindering the uptake of biological alternatives in developing countries. Existing biological alternatives may not be available or affordable; their viability in the relevant environments may not have been adequately demonstrated; and technical knowledge, including capacity for handling and promoting alternatives, is weak. Further challenges are the lack of effective research and monitoring programs to provide reliable data on the toxicology and levels of POPs in the environment (and on the impact of alternatives when introduced); in some cases, high costs and long lead times associated with developing and assessing alternatives; and in almost all cases, an inadequate policy and legislatory environment and weak enforcement of existing regulations banning POPs and promoting their proven alternatives.

The need to overcome these barriers was the rationale for a workshop held at the International Institute of Tropical Agriculture (IITA) in Benin in 2004. Entitled 'The search for alternatives to banned/restricted POPs in Africa', the workshop was a joint endeavor by UNIDO and the SP-IPM of the CGIAR. The workshop brought together 61 participants from 20 African countries, including national and technical coordinators of POPs reduction programs, researchers from national and international research institutes and universities in Africa and, from France and the USA, representatives of the biocontrol industry. This Research Brief is based on discussions and outputs of that workshop. Focusing on finding and implementing alternatives to the eight pesticide POPs (see Table 1), it presents an overview of the current status of biological alternatives to dangerous chemical pesticides, and of the issues that need to be addressed to enable their widespread use by small-scale farmers in developing countries.

Participants at the UNIDO/SP-IPM workshop held in Benin in 2004

Table 1. Uses of the eight pesticide POPs targeted for elimination by the Stockholm Convention

POP pesticide	Known uses
Aldrin	Against termites in the soil, other soil pests, termites attacking building materials, grain storage pests, and for disease vector control
Camphechlor (toxaphene*)	Control of insect pests in cotton and other crops
Chlordane	Against termites and other soil pests, termites attacking building materials
DDT	Control of human and animal disease vectors, e.g. malaria-transmitting mosquitoes, plague-transmitting fleas, trypanosomiasis-transmitting tsetse flies
Dieldrin	Control of locusts, termites, human disease vectors
Endrin	Formerly used against insects and rodents. No current or recent uses are known
Heptachlor	Against termites and other soil pests, termites attacking building materials
Mirex	Against leaf-cutting ants, termites in buildings and outdoors, and also as a fire retardant and for other industrial purposes

**Camphechlor is the generic name, while toxaphene originally was a trade name. The latter is often erroneously used as a generic name.*

Source: IOMC, 2002

Integrated Pest and Vector Management

Integrated pest management provides alternative ways to manage crop pests and diseases, instead of using POPs and other harmful agrochemicals. IPM builds on traditional, appropriate pest and disease management strategies that farmers have used for centuries, and combines them with new technologies based on ecologically sound principles, to manage pests and diseases effectively with minimum impact on the environment. Farmers make informed decisions in selecting from a range of effective and affordable pest control methods that do not damage the ecosystem within which they grow their crops. Good cultural practices to ensure vigorous crops, resistant crop varieties, and biological control of pests are the mainstays of IPM. Chemical pesticides are used only when these measures fail to keep pests below acceptable levels, and when the benefits of their use outweigh the costs.

The SP-IPM partners support and promote IPM and its adoption by farmers. As well as carrying out collaborative research and related activities, the partners support the development of a policy environment favorable to the adoption of more sustainable crop protection strategies. The SP-IPM position on synthetic chemical pesticides is given in the box on page 8.

Integrated vector management (IVM) follows the same principles as IPM. It aims to control disease-carrying insects (vectors) through a combination of locally appropriate interventions which cause minimum disruption to the ecosystem. Environmental management and personal protection against insects, for example through the use of mosquito nets, are the strategy of first choice in IVM. Biological control of insect vectors is an important second line of action. Chemical intervention is used as a last resort.

Several insect-borne diseases have significant global impact, but by far the most important is malaria. There are at least 300 million acute cases of malaria each year, with more than a million deaths. About 90% of these deaths are in Africa, and most are of young children. DDT has played – and continues to play – an important role in the fight against malaria. A significant challenge for IVM is removing the reliance on DDT in malaria control.

Biological Alternatives

IVM is a relatively new approach to disease control, while IPM is longer established, with lessons that can be useful for IVM. The similarities in strategies, and the strong links between agriculture, health and environment, mean that combined integrated pest and vector management approaches may be the way forward. The overall aim is to protect crops from pests, communities from insect-borne diseases, and local ecosystems from harmful chemicals in a holistic, locally driven way.

The SP-IPM Position on Use of Synthetic Pesticides

In recognition of the international limitations on pesticides provided in projects supported by the World Bank and FAO;

In recognition of the socio-economic limitations facing small-scale farmers, farm workers and households in avoiding exposure to pesticides or gaining access to appropriate protective gear;

In recognition of the significant dangers involved in the transport, storage, formulation and application of toxic products in the agricultural sector;

In recognition of the harmful productivity, environmental and health impacts of the most toxic pesticides, and

With the goal of moving towards cleaner production systems, including IPM research and practice, the SP-IPM strongly urges its partners that:

- IPM research should exclude POPs, Class I and where feasible Class II compounds as components of IPM recommendations.
- POPs, Class I and, where feasible, Class II compounds should not be included as components of IPM strategies and programs.
- Research, development and training should focus primarily on non-toxic or low-toxic (e.g. Class U, biological organisms) methods, materials and relevant policy within IPM programs.

Chemical Pesticides versus Biological Alternatives

Chemical pesticides are quick and easy to use, and are effective: farmers see rapid responses following application. They are also produced relatively cheaply, easily stored for long periods of time, and are readily available through a long-established market.

IPM requires more knowledge and skills for success. The results often take longer to materialize. Some technologies, for example biopesticides, are currently not readily available, particularly in developing countries. And costs are at the moment generally higher than for chemicals.

This simple comparison goes some way to explaining why chemical pesticides are currently more widely used than biological alternatives; but it also hides the true costs and benefits of these different approaches. The environmental and health costs of chemical pesticides, though difficult to quantify precisely, can be very high (see ‘The Real Dangers of POPs’ on page 4). They are also not immediately obvious. Farmers are usually unaware of these costs, so that they are not making an informed decision when selecting chemicals. The monetary cost of chemicals is also often distorted by subsidies.

Chemical pesticides work against nature, disrupting ecosystems. As well as killing the target pest they also kill other species, some of which may be useful, for example natural enemies of the pest, or pollinators. Ecosystems are finely balanced, dynamic systems that have evolved over time, and the rapid destruction of several species can unbalance the entire system. Previously insignificant pests may rise in prominence within the destabilized system, creating new sources of crop losses. In addition, pests can become resistant to chemicals so that larger doses are needed for the same effect, thereby increasing ecosystem damage. A vicious cycle develops, with increasing production costs, declining yields, and rising levels of damage to the environment and human health.

Biological alternatives, in contrast, work with nature. Biological control, for example, uses natural enemies – predators, parasitoids or pathogens – to reduce pest populations and the damage they cause. In some cases these methods build on the natural control already occurring within an ecosystem, by boosting a naturally occurring enemy; in others they involve importing and introducing a natural enemy, especially where the pest itself has been introduced. The effects of any introduced or applied biological control agent are very specific – candidate species for introduction are carefully screened to this effect – and species other than the target are not usually affected. In using IPM, farmers learn to understand the dynamics of their ecosystem, and to manipulate it where necessary to reduce crop damage.

Chemical pesticides are usually used to reduce pest populations when they have reached high levels and damage is visible. This approach is straightforward for farmers, as the problem becomes easy to diagnose, and it is effective because chemicals are fast-acting. Some biological alternatives follow this same strategy, which has contributed to their success as alternatives to chemical pesticides. Others are slower acting and require a different strategy. Rather than intervening when a pest population has reached a damaging threshold, farmers using these alternatives learn to intervene early, maintaining pest numbers at low levels. This approach requires more knowledge of crop pests and diseases, and of agro-ecosystems, on the part of farmers.

Chemical versus Biological Control: the Case of the Rice Brown Planthopper in Southeast Asia

Chemical pesticides accompanied new high yielding rice varieties as the main Green Revolution technologies introduced to Asia in the 1960s. In the 1970s the rice brown planthopper, *Nilaparvata lugens*, an indigenous and previously innocuous insect, started to become a major rice pest in Southeast Asia. The two events, it is now known, were not unconnected.

First attempts to deal with the pest focused on developing and disseminating resistant rice varieties, and at the same time increasing pesticide applications. In Indonesia for example, massive seed production programs kept farmers supplied with the most recently developed resistant varieties, and pesticides were subsidized to the tune of US$100 million per year between 1980 and 1987. But these measures failed, and indeed exacerbated the problem. The planthoppers quickly adapted to the new varieties and developed pesticide resistance, while the pesticides killed natural enemies of the planthopper. Populations of the pest, and crop damage, soared: the vicious cycle was set.

Then IPM specialists stepped in. They demonstrated the role of predators (*Lycosa* spiders, and *Cyrtorhinus* and *Microvelia* bugs) and egg parasitoids (*Anagrus* and *Oligosita* wasps) in natural biological control of planthoppers, which was currently being interrupted by chemical insecticides. The scientists lobbied for action to break the pesticide cycle, and in 1986 in Indonesia 57 pesticides were banned from use on rice, while subsidies for pesticides began to be removed. At the same time, extensive farmer education was conducted through farmer field schools. The result was a drastic reduction in pesticide usage, and before long, balance was restored. Yields remained constant, and *N. lugens* ceased to be a major concern in Indonesia, except in areas where banned pesticides are still used.

This successful scenario of pesticide reduction, favoring local natural enemies, and supported by training of farmers has since been repeated in other rice-growing regions, and also for many other crops across the world.


Rice on sale in the Philippines

Biological Alternatives

The Biological Alternatives

The IPM and IVM approaches offer many and diverse biological alternatives to chemical pesticides. Cultural practices that maintain vigorous crops that are less vulnerable to attack by pests and diseases, increasing crop diversity through rotations or intercropping, use of clean seed or other planting materials, adjusting planting dates to avoid peaks in pest populations, and good sanitation in storage buildings are all examples of effective non-chemical ways of reducing crop losses due to pests and diseases. Crops with genetic resistance or tolerance to pests and diseases are also a vital tool in the IPM toolbox. And presenting a barrier to mosquitoes with nets is a proven way to reduce malaria.

Many biological alternatives can be used as relatively straightforward replacements for chemicals. These alternatives provide the focus for the remainder of this Research Brief. They are grouped as follows:

- Biological Control
- Biopesticides
- Botanicals
- Semiochemicals
- Transgenic Organisms.

There is some overlap among these groups. Biological control, or biocontrol, is the use of natural enemies to reduce the damage caused by pests. Natural enemies are predators or parasitoids that attack the pest, and are usually insects or other arthropod species – they are also called biological control agents. Pathogens – micro-organisms that cause disease – are the key ingredient in biopesticides, which usually kill the pest. But natural enemies may also be pathogens, in which case the biopesticide can be classified as a type of biological control. The term biopesticide may also be used more widely, to describe the application of large numbers of any biological control agent – whether pathogen, predator or parasitoid. Indeed, botanicals, semiochemicals and even transgenic plants may sometimes be described as biopesticides, as for example by the US Environment Protection Agency which uses the following inclusive definition: "Biopesticides are certain types of pesticides derived from such natural materials as animals, plants, bacteria, and certain minerals." Our working definition is provided at the beginning of each of the following sections.

Of the types of intervention listed above, biological control and biopesticides are the ones that most often tend to be used following a chemical pesticide model. Applying large amounts of a fast-acting biopesticide when a pest has reached economically damaging levels is a relatively easy approach that farmers familiar with chemicals can apply. However, many researchers believe that the real value of biological control and biopesticides lies in the capacity of the control agent to reproduce and spread itself. To take advantage of this, small amounts of biopesticide can be applied early in the crop season, so that the population of the control agent can establish and increase to keep the pest in check throughout the season. This approach is much cheaper for farmers, but it requires considerably more knowledge and skills than inundative application, and has not so far been fully exploited.

Biological Control

Insects, mites, micro-organisms and other species that prey on or parasitize different species are part of the natural control or balancing mechanisms that occur in undisturbed ecosystems. Humans can intervene to boost this natural activity in agro-ecosystems, wherever a pest with a known natural enemy threatens crops and/or spreads disease.

Sturmiopsis parasitica - a tachinid parasitoid of maize stemborer

There are three different approaches to biological control. In conservation biological control, action is taken to enhance the effectiveness of the natural enemies already present in the ecosystem. This may involve planting food sources for natural enemy species, providing suitable nesting sites for these species, or reducing the amount of synthetic chemicals in a system to allow natural enemy numbers to increase. Augmentation biological control means adding a predator or parasite to an ecosystem, either to boost existing numbers or to begin a new population where the natural enemy has disappeared. If small numbers are added and the species naturally increases over time, this is termed inoculation; if large numbers are applied for rapid effect on the pest, this is called inundation.

A third approach is importation of a natural enemy to a region where it has not been present before. This is also known as classical biological control, and is usually appropriate when the pest itself has been accidentally imported. Such importations need international cooperation and a great deal of research. Natural enemies found in the original habitat of the pest are screened in a quarantine laboratory to exclude unwanted organisms. Usually, acceptable natural enemies are highly specific, so that they do not pose any threat to non-target indigenous organisms. Inoculative releases follow, and are carefully monitored to see whether the imported natural enemy can adapt to the new conditions and whether it spreads on its own.

Classical biological control has been applied successfully to control hundreds of pest species, mostly insects and mites,

Biological Control of the Cassava Mealybug in Sub-Saharan Africa

The story of cassava mealybug in sub-Saharan Africa represents one of the most successful classical biological control projects of all time. It is also a showcase of effective planning and implementation of such a project on a continental scale.

When the mealybug pest, *Phenacoccus manihoti*, was accidentally imported from South America in the 1970s, it quickly became a very serious threat to one of Africa's most important staple crops, cassava. Cassava also originates from South America, and this was the logical place to seek a natural enemy. Researchers found that, in that region, the mealybug is largely kept in check by a parasitic wasp, *Anagyrus lopezi.* The wasp uses the mealybug as a host for its eggs, and the developing larvae kill the mealybug.

Anagyrus lopezi, a parasitic wasp that preys on the cassava mealybug

The next stage involved intensive research to be sure that introducing the wasp to Africa would not create further ecological problems, for example, that the wasp would not attack indigenous organisms, such as bees or other natural enemies. Only when scientists were convinced this would not be the case was the wasp brought to Africa, reared in special facilities at IITA in Cotonou, Benin and released. The wasp began controlling the mealybug almost immediately, and a measurable reduction in damage was seen in the first season following release. Within 2–4 years mealybug populations had been reduced to 10% of peak numbers, a level of control that continues today. Recreating the natural balance between pest and natural enemy in sub-Saharan Africa effectively saved cassava for the region's resource-poor farmers.

on horticultural and field crops and in forestry. This approach is self-perpetuating and, despite initially high investment costs, is ultimately the most economical form of pest control. The natural enemies are, however, highly susceptible to chemical pesticides, the use of which often leads to resurgences of previously well controlled insects and mite pests.

Table 2 lists some predators and parasites that have been used successfully for biological control. Some of them are commercially available, mostly in Europe, North America, India, China, Brazil, Kenya and South Africa. Very many more natural enemy species are exploited locally or regionally. Two examples of conservation and classical biological control are described in detail in the boxes.

Biopesticides

Biopesticides, or microbial pesticides, have a pathogenic micro-organism as their active ingredient, for example a bacterium, virus, fungus, nematode or protozoa. They are often applied in a similar way to chemical pesticides, but their 'live' ingredient gives them a potentially great advantage over chemicals, as they are able to reproduce and so to provide continuing pest control.

Biopesticides currently comprise a tiny proportion of the global pesticides market – probably less than 2%. They are mainly used in developed countries, where appropriate regulations are in place for their registration and use, and they mostly serve a niche market for 'organic', environmentally friendly products. The demand for chemical pesticides has gradually declined in these countries over recent years, yet biopesticides have failed to significantly increase their share of the market. The reasons for this are discussed under 'A New Paradigm', on page 22.

The potential for biopesticide use in developing countries is also underexploited at present. However, some of the most successful examples of this approach to date have been in developing countries. Soybean farmers in Brazil have been successfully deploying nuclear polyhedrosis virus (NPV) to control the velvetbean caterpillar for several years, while in China farmers of the same crop have used the fungus *Beauveria bassiana* against a different pest, the soybean podborer, again with great success.

Table 3 gives details of some biopesticides currently in use. Several of these are also discussed below, and some examples of their successful use are presented in the boxes.

Bacillus thuringiensis

Biopesticides based on *Bacillus thuringiensis*, or Bt, are currently the most widely produced, accounting for 90% of the


The diamondback moth (Plutella xylostella), a pest on brassicas


Diamondback moth larva infected with granulovirus

Table 2. Some arthropod predators and parasites commonly used in biological control

Control agent	Target pest(s)	Crop	Commercially available
Predators			
Rodolia cardinalis (the first modern example of use of a lady beetle)	Cottony cushion scale	Citrus	No longer
Exochomus, Hyperaspis, Hippodamia, Coccinella (and many other lady-beetles)	Aphids, whiteflies, scale insects, mealybugs	Fruit trees, most crops	
Chrysoperla (green lacewings)	Aphids, whiteflies, thrips, mealybugs	Horticultural crops, glasshouse crops, field crops	Yes
Orius (minute pirate bug)	Thrips, aphids, whiteflies	Fruit trees, cotton	Yes
Geocoris (big-eyed bugs)	Whiteflies, mites, aphids, most Lepidoptera	Fruit trees, cotton	No
Aphidoletes (predatory midge)	Aphids, mites	Fruit trees, field crops	Yes
Neoseiulus, Phytoseiulus, Galendromus, Euseius, Iphiseius (and other predatory mites)	Spider mites, thrips, whiteflies	Fruit trees, field crops, cut flowers	Some yes
Typhlodromalus aripo, T. manihoti	Cassava green mite	Cassava	No
Parasites (parasitoids)			
Trichogramma spp.	Moths	Maize, fruit trees	Yes
Encarsia, Cales, Eretmocerus	Whiteflies	Fruit trees	Yes
Anagrus spp.	Leafhoppers	Fruit trees, grapes	Yes
Anagyrus, Gyranusoidea spp.	Mealybugs	Trees, field crops	Some yes
Apanteles, Cotesia, Bracon	Lepidoptera	Field crops, vegetables, cotton	Yes
Diglyphus, Hemiptarsenus	Leaf miners	Field crops, trees	Some yes
Aphytis, Aonidiella	Scale insects	Fruit trees	Some yes
Opius, Diachasmimorpha, Fopius	Fruit flies	Fruit trees	Some yes
Tachinid flies	Caterpillars, beetles, bugs, grasshoppers	Sugar cane, etc.	Yes

Biological Alternatives

Table 3. Some biopesticides, their target pests, and area of application

Control agent	Target pest(s)	Examples of use	Commercially available as
Bacteria			
Bacillus thuringiensis israelensis (Bti)	Larval stage of mosquitoes, blackflies, some gnats	Disease vector control	Vectobac, Skeetal, Bactimos
B. thuringiensis kurstaki	Larval stage of various lepidopteran insects (caterpillars), e.g. cabbage 'worms', diamondback moth, leafrollers, maize borers	Crop protection in the field and in storage(cereals, forage crops, vegetables, fruit)	Biobit, Dipel, many others
B. thuringiensis tenebrionis	Larval stage of various beetles, e.g. Colorado potato beetle and elm leaf beetle, and boll weevil	Crop protection	Trident, Norodor
B. sphaericus	Larval stage of some mosquito species	Disease vector control	VectoLex
B. popilliae	Some scarabaeid beetles, particularly chafers, e.g. Japanese beetle and European corn chafer	Crop protection	Doom, Japademic
B. subtilis	Disease-causing fungi including *Rhizoctonia*, *Fusarium*, *Alternaria* and *Aspergillus*	Crop protection (cotton, vegetables, peanuts, soybean)	Kodiak, Epic
Serratia entomophila	Grass grub, root knot nematode	Pasture and crop protection	Invade
Viruses			
Nuclear polyhedrosis viruses, granulosis viruses, non-occluded baculoviruses	Many insects, e.g. cabbage moth, diamondback moth, potato tuber moth, cotton bollworm, beet armyworm, alfalfa looper, gypsy moth, codling moth	Crop and forest protection	Mamestrin, Biotrol, Spod-X, Gypchek, Cyd-X
Fungi			
Beauveria bassiana	Adults and larvae of many insects, including whitefly, aphids, thrips, and mealybugs	Crop protection (field crops, vegetables, fruits)	Mycotrol, BotaniGard, Naturalis
Metarhizium anisopliae	Many insects are susceptible. Used against desert locusts, termites, thrips	Field crop protection (locusts), protection of buildings (termites)	Green Muscle and Green Guard for locust control; BioBlast for termite control
Entomophaga	Grasshoppers, gypsy moth, other insects	Field and forage crop protection; forest protection	Not commercially available
Paecilomyces	Whiteflies, aphids, thrips, some nematodes	Crop protection	PFR-97
Neozygites floridana	Cassava green mite	Crop protection	

Table 3. Some biopesticides, their target pests, and area of application (continued)

Control agent	Target pest(s)	Examples of use	Commercially available as
Protozoa			
Nosema spp.	Grasshoppers, caterpillars	Field and forage crop protection	Locucide
Vairimorpha spp.	Caterpillars	Crop protection	Not commercially available
Nematodes			
Steinernema	Larvae of vine weevils, fungus gnats, scarab beetles, dipterous flies, webworms, cutworms, armyworms, and other insects		BioVector, BioSafe
Heterorhabditis	Black vine weevil, root weevils, soil insect pests		Otinem, Cruiser

global biopesticides market. Their success is largely due to their similarity to chemicals and their ease of use; indeed, their active ingredient is essentially a molecule, as in chemical pesticides. They were first produced commercially in the USA in the 1960s.

The bacterium *Bacillus thuringiensis* occurs naturally in the soil and on plants. Many subspecies or varieties have been identified, but most biopesticide products are currently based on one of four: *B.t. aizawai*, *B.t. israelensis, B. thuringiensis kurstaki* and *B.t. tenebriosis*.

Bt biopesticides are used against certain Lepidoptera (moths and butterflies), Diptera (flies) and Coleoptera (beetles). They become effective when they are eaten by the larvae of susceptible species, in which they damage the gut, usually leading to death within an hour to a few days. These effects are due to toxic protein crystals produced during spore formation. Five different crystal 'families', named CryI–CryV, have been identified, each with specific toxicity to certain insects or insect groups.

Commercial Bt biopesticides are available as sprays, wettable powders, liquid concentrates and dusts. To be effective, they must be applied evenly to areas of the plant where larvae are present and actively feeding. Some products have a mixture of different Cry toxins and Bt spores, developed to boost insecticidal activity and pest range. However, Bt products remain active for a relatively short period (several days to several weeks) and, unlike the active ingredient of

Beauvaria attack on Clavigralla tomentosicollis some biopesticides, do not reproduce to perpetuate the control effect. Sunlight can reduce effectiveness, as can rain if it washes the biopesticide off the plant. There is also a potential problem with resistance. Although not initially apparent, resistance has been reported in the past two decades from both the field and the laboratory.

Fungi

Many insect-killing fungi are known in nature, making them good candidates for biopesticides. Several have so far been developed to various stages, with those based on *Beauveria bassiana* and *Metarhizium anisopliae* the best known. Both of these attack a relatively wide range of insects, making them

Fighting Locust Swarms with Mycopesticides

The devastating desert locust swarms that affected northwest Africa in 2004 and 2005 were the latest in a long history of intermittent locust plagues and upsurges that regularly cause huge amounts of damage to crops and despair for farmers, together with acute food shortages. As demonstrated by this latest outbreak, which is estimated to have caused US$2.5 billion worth of damage to crops, current locust control measures are largely failing to deal with the problem. Limited resources for monitoring and control, the difficulties of predicting outbreaks and of maintaining sufficient trained staff and functioning resources during the gaps between outbreaks, and the nature of locust swarming – their rapid spread over vast and often inaccessible areas – all contribute to this failure. Control, mostly with chemical pesticides, is usually carried out as an emergency measure once swarms are already large and on the move – but any form of crop protection is futile once the swarms have landed.

The recent upsurge did, however, provide an opportunity for the first large-scale testing of a fungal biopesticide called Green Muscle®. This product had been developed as a response to the 1986–89 locust plague, when some 1.5 million litres of chemicals caused considerable (though unmeasured) environmental and human health damage. Based on a variety of the fungus *Metarhizium anisopliae* commonly found throughout the tropics and sub-tropics, the breakthrough in the development of Green Muscle came with the discovery that the fungal spores could be suspended in oil, where they remain effective in prolonged dry conditions. Many years of development and testing resulted in a product that is effective against most locust and grasshopper species, has no effect on other species, is stable with a relatively long shelf life, and can be sprayed using standard spraying equipment, with aerial application possible over large areas. The 2005 trial saw Green Muscle sprayed over 1400 hectares in eastern Algeria. Locusts were visibly weakened within 4 days, and then died or were eaten by birds, lizards and ants. Although the biopesticide takes longer to kill than most chemical pesticides, the effect is prolonged as infection continues to occur. In one trial, 16 days after spraying grasshopper numbers were still down 95%, while in plots sprayed with chemical insecticide numbers had recovered completely to pre-spray levels.


Locusta migratoria

Under the right conditions, Green Muscle is clearly effective and could provide a much-needed alternative to chemical pesticides for locust and grasshopper control. Its widespread use now depends on its successful commercial development. A small South African company is currently licensed to make and sell it, and has the capacity to produce 5 tonnes per year. It has registered the product in South Africa, Namibia, Zambia, Tanzania and Sudan. However, building adequate stocks to combat future locust upsurges is not economically feasible for a small company operating on its own. In Australia a similar product, Green Guard®, has been backed by the Australian Plague Locust Commission. With guaranteed uptake by the Commission, the manufacturer has been able to expand production so that significant quantities are available when needed. A similar arrangement could be the way forward for Green Muscle.

IPM Research Brief No. 4

Biopesticides for Malaria Control

Malaria, which is caused by a protozoan parasite, is transmitted to humans by the *Anopheles* mosquito, and efforts to control the disease have largely focused on reducing populations of these insects by spraying with chemical insecticides such as DDT. Just a few decades ago it was hoped that this approach, combined with treatment of the disease with the drug chloroquine, could eradicate malaria worldwide, but this ambitious program failed. Malaria returned with a vengeance in the 1970s, compounded by mosquito resistance to DDT and new strains of the parasite resistant to chloroquine. Changes in human activities and other factors have added to the problem, for example, population movement and urbanization, increased irrigation of crops, and climate change have all been linked with increased incidence. Today malaria is once again a leading cause of death globally, and quick-fix solutions are no longer sought. Instead, control depends on a range of interventions, and the use of local knowledge, effective collaboration, and an enabling public health and legislative framework – in other words, IVM.

Biological control plays an important part in the IVM approach. There are proven biological control measures that can keep mosquito populations in check. Bacteria-based biopesticides that kill the mosquito larvae have so far been the most successful, in particular those based on *Bacillus thuringiensis israelensis* (Bti) and *Bacillus sphaericus* (Bs). Applied as a spray to mosquito breeding sites, Bti products have been used against mosquitoes in some countries for more than 20 years. They have rapid action, achieving high larval mortality in about 48 hours, and resistance has not so far arisen, probably because of the multiple toxin complex of the bacterium. No toxic effects have been recorded in mammals or aquatic species, or in other non-target species. Bs products are also effective against *Anopheles* and some other mosquitoes, and have the advantage of longer activity as the bacteria survive and reproduce, unlike in Bti products. Resistance to Bs has, however, been recorded.

A malaria control program in the late 1990s in Managua in Nicaragua showed these two biopesticides to be extremely effective for malaria control as well as being much cheaper than chemical pesticides. A combination of one to two applications of a Bs product and three to five applications of a Bti product annually was enough to provide adequate control of mosquito populations, and the number of malaria cases in the city dropped from over 19,000 in 1996 to 1575 in 2000. Practical training of Health Ministry technical staff was crucial to the success of the program. Staff learned to identify larval growth stages, to calculate larval densities, to recognize when to implement control measures, and to understand simple ways of increasing the effectiveness of biopesticides, such as by cutting back vegetation around breeding sites before spraying.

Fungus-based biopesticides may also soon join the armory in the fight against malaria. Recent research has shown that the fungi *Beauvaria bassiana* and *Metarhizium anisopliae* infect *Anopheles* mosquitoes, greatly reducing their ability to transmit the disease before killing them. There are some potential advantages over bacterial biopesticides: adult mosquitoes are vulnerable, and the fungal spores penetrate the insect so there is no need for the biopesticide to be ingested.

One factor limiting the deployment of biopesticides against malaria is the absence of production facilities in developing countries, where the problem is most acute. Lack of appropriate national regulatory frameworks for biopesticides, combined with low market incentives, have restricted the development of a biopesticide industry in many developing countries. Sustained efforts to increase involvement of the private sector, to develop public–private sector partnerships, and to build capacity for appropriate biopesticide regulation may hold the keys to successful biological control of malaria vectors in developing countries.

A mosquito, the malaria vector

more likely to be commercially viable. A great advantage of fungal biopesticides, or mycopesticides, is that they do not need to be ingested, but attack and penetrate the insect through its cuticle. This makes them useful against sucking insects such as whiteflies and aphids, which are not susceptible to bacterium- or virus-based biopesticides because they do not feed on external plant parts. They have also proved very effective against locusts, grasshoppers and leaf-feeding caterpillars.

Mycoherbicides for weed control also have potential as biological alternatives to chemical herbicides. For example, *Fusarium* spp. have shown promise as the basis for mycoherbicides. *Fusarium oxysporum* may prove useful against *Striga* and *Orobanche* spp., parasitic weeds which cause huge losses to farmers in developing countries.

Botanicals

Botanical pesticides contain plant extracts that have biocidal properties. They have the advantage that farmers can often self-supply, either from wild areas on or near their farms or by growing the pesticide-providing plants alongside their crop plants. In India, for example, farmers have for centuries used extracts from nearby neem (*Azadirachta indica*) trees to protect their crops.

Neem is one of the best known and most effective botanical pesticides. The active ingredient, azadirachtin, has the same activity as an insect hormone and can be used to disrupt moulting in a range of insect pests. As well as locally sourced neem, there are many commercial companies producing neem products, using high-tech extraction processes. An intermediate technology, based on small-scale local commercial production, may be appropriate for developing countries and is under trial in Kenya, West Africa and the Lake Chad Basin.

Pyrethrin is another highly effective botanical insecticide. It is derived from flowers of *Chrysanthemum cinerariaefolium*, which are widely grown for this purpose in some African countries. More botanicals are under investigation, while many others almost certainly remain to be discovered. One recently identified is finotin, an extract from the tropical legume *Clitoria ternatea*. Showing a broad range of activity against insects as well as bacterial and fungal pathogens, it has been demonstrated that a crude extract prepared by grinding the seeds is highly effective, protecting crop plants from a wide range of pests and diseases. The researchers who identified this new botanical pesticide believe that farmers could easily grow *Clitoria ternatea* alongside their crops and extract and apply finotin as needed. Local commercial production by small companies is also being investigated.

Table 4 gives details of some botanical pesticides.

Semiochemicals

Insects and other species produce chemicals that stimulate particular behavior or interactions between individuals. These are called semiochemicals, and they can be used to manipulate behavior in order to control pests. There are two

Pheromone Traps for Cowpea Podborer Control

Cowpea is an important crop in West Africa, growing on poor soils and providing much-needed protein in people's diets. But cowpea farmers face an ongoing struggle with many pests. *Maruca vitrata*, the legume podborer, is one of the most damaging, causing losses of up to 80%.

Cowpea farmers in Benin, Burkina Faso and Ghana are beginning to experiment with pheromone traps that show the presence of the podborer, and indicate population densities, so that they know when to apply control measures. If chemical pesticides are used, this approach reduces the amount applied and therefore the damage caused.

The effectiveness of the traps is based on research findings that numbers of the adult moths increase several days before the larvae begin to damage the cowpea crop. The research also defined the threshold for action. Once farmers see an average two moths per trap in at least six traps, they are advised to apply a control measure, such as an insecticide, within 3 days.

Traps are made from local materials, such as plastic jerrycans, so that they are cheap and easily available. Water is used inside the trap to kill the moths by drowning them. Lures containing the pheromone are supplied by a small company in the UK, and last for up to 4 weeks in the field. In the future, it is hoped that the market for pheromone traps will expand, and local manufacture of traps and lures will be feasible.

Table 4. Some botanical pesticides, their target pests, and area of application

Control agent	Target pest(s)	Examples of use	Commercially available as
Neem (extracted from *Azadirachtin indica*)	Many insects, including aphids, beetles, caterpillars, leafhoppers, mealybugs, thrips and whiteflies	Crop protection (field and storage)	Neemix, Aza-Direct
Pyrethrins (extracted from *Chrysanthemum cinerariaefolium*)	Lice, mosquitoes, cockroaches, beetles, flies; also harmful to fish	Insect repellant	Buhach, Ofirmotox
Rotenone (extracted from some tropical legumes)	Insects, mites; also harmful to fish	Weed killer	Liquid Derris
Ryania (extracted from *Ryania speciosa*)	Various insects, e.g. fruit moth, corn moth, European corn borer, citrus thrips	Crop protection	Natur Gro R-50, Ryanicide
Finotin (extracted from *Clitoria ternatea*)	Broad range: insects, bacteria, fungi etc.	Crop protection	Not yet available

types: pheromones stimulate behavior between individuals of the same species, while allelochemicals mediate interaction between different species. Semiochemicals can also be grouped by the behavior they elicit, for example, attractants, repellents, deterrents, stimulants, etc.

Insect sex pheromones are the most useful semiochemicals in IPM. They are attractants, usually produced by

Small-scale local production of neem products is in progress in Kenya females to attract males. Hundreds of insect sex pheromones have been identified, and synthetic versions of many of these have been produced, some proving even more attractive to the male than the natural compound. Their main uses are to disrupt mating, so restricting pest population growth, and in traps, for detection and monitoring of pest species. Mating is disrupted using slow-release pheromones that give a continual low concentration of pheromone and cause the male to repeatedly attempt to mate without a female, or to become habituated to the pheromone so that he no longer responds to it. Traps draw in males, where they are then killed, for example by contact with a sticky surface or by a synthetic pesticide. Farmers can thus see that the pest is present, and as numbers in the traps increase they can decide when to implement control measures.

Trapping large numbers of males may also serve to control the pest, as fewer males will be available for mating. However, this approach may not be realistic, as it may require trapping as many as 95% of males – otherwise the remaining males simply mate more frequently.

A promising recent advance is the combined use of pheromone traps with a fungal biopesticide, in which the lured individual gets infected and is then released to spread the fungus to other healthy individuals.

Transgenic Crops

Transgenic crops containing plant-incorporated protectants make up a further group of biological alternatives. The protecting substance is produced by the plants themselves following the introduction of genetic material coding for that substance. Bt transgenic plants are the best known example; the gene coding for the Bt toxin is inserted into the chromosome of the crop plant so that the plants themselves become toxic to the pest. Bt varieties of maize, potato and cotton are today widely grown in some countries.

Transgenic crops have enormous potential for resource-poor farmers, as a low-cost and environmentally friendly way to manage pests and diseases, as well as other threats or constraints, such as drought and human vitamin A deficiency. The crops and the traits of relevance to small-scale farmers in developing countries have, however, received little attention, mainly because most of the research on transgenics has been conducted by the private sector. Research and industry need to address this imbalance. Measures that can help include developing science-based regulatory procedures for the testing and release of transgenic crops in developing countries, ensuring the protection of intellectual property rights, strengthening research capacity in national systems, and promoting public–private partnerships.

Bt Cotton

Cotton is highly susceptible to insect pests – it has been estimated that as much as 25% of all agricultural pesticides are applied to the crop. DDT has been widely used, as well as organophosphates and pyrethroids, and many cotton pests have developed multiple resistance to these chemicals. Cotton is an important cash crop in developing countries, so when Bt insect-resistant cotton was developed and first grown in the USA in 1996, its potential in these countries soon became clear. Today, Bt cotton is the transgenic crop most widely grown in developing countries, having spread rapidly among farmers in Argentina, China, Colombia, India, Indonesia, Mexico and South Africa. Pesticide use has been significantly reduced, saving farmers both money and time, as well as reducing health and environmental costs. Studies comparing the gains from Bt cotton in different countries have shown that its yield advantage is higher in developing countries, as this is where farmers typically lose more to pests.

The success of Bt cotton is not necessarily a predictor for other transgenic crops in developing countries. Most crop varieties, including transgenic crops, need to be adapted for local agro-ecologies and cannot simply be transferred from one place to another. Indeed, many developing country crops are not widely grown outside a specific country or indeed region, so transgenic versions of such crops would need to be nationally developed. The spread of such crops will therefore depend on strong national research capacities, as well as effective public–private partnerships. However, the Bt cotton story does provides some useful indicators for the successful adoption of transgenic crops by resource-poor farmers: all the countries where the crop has proved successful have good biosafety protocols in place; and all have good seed delivery mechanisms, some of which target small-scale farmers.

IPM Research Brief No. 4

Knowledge Tools

Choosing biological alternatives to chemical pesticides is rarely a straightforward decision for a farmer. There are usually several options for a particular pest problem, and farmers will need to decide which one, or more often which combination, is best – and appropriate and feasible – for their situation. A farmer may want to evaluate the different options and combinations and compare them with the chemical option, before deciding which to use. Farmer field schools, and the various other farmer participatory research and/or training approaches, help farmers learn about the different options as a basis for making informed decisions.

Farmer field schools equip farmers with 'knowledge tools' that enable them to improve their management of crop pests . For example, farmers may learn about the benefits of regular scouting to estimate the numbers of pests and natural enemies in the field, and to understand how pests affect the crop at different stages of development. They may also learn the methods of agro-ecosystem analysis, in which observations are made and recorded regularly on crop growth stages, presence and abundance of pests and natural enemies, weather, soil, and overall plant health. Different pest management methods can be compared within this analysis, including new alternative methods and farmers' own methods. In this way, farmers' decisions on which methods to

Farmers evaluate biopesticides in field trials

Chemicals or Botanicals: Farmers Decide

Cowpea farmers in West Africa face an ongoing struggle with many pests, such as aphids, leafhoppers, thrips and podborers, that can severely damage their crop. Many resort to chemical pesticides, as these are readily available in the region. But they are often unaware of the dangers associated with these chemicals, which are not intended for food crops but for cotton, and poisoning is common. The African Cowpea Project (Projet Niébé pour l'Afrique, or PRONAF) therefore set up farmer field schools to introduce farmers to alternatives to the chemicals, and to help them evaluate these options in the field. The alternatives included neem extracts; other botanicals extracted from pepper (*Hyptis suaveolens* and *Boscia senegalensis),* which were farmers' traditional control methods; new cowpea varieties with tolerance to some of the major pests; and solar drying to limit pest damage in storage.

Farmers learned about cowpea pests and natural enemies, and the effects and dangers of using chemicals on their cowpea crops. In many of their experiments, they saw that the botanicals performed better than the chemical pesticides. They were particularly impressed with the effects of neem, and to learn that it was readily available (from trees growing nearby), although the lengthy preparation of the extract by grinding the leaves was considered a disadvantage. Information on the use of neem and other botanical extracts as alternatives to chemicals was frequently shared with other farmers outside the farmer field school.

As one Ghanaian farmer explained, "Now we know the various insects and that some are beneficial and eat the others which destroy our cowpea crop. What interested us more is that neem leaves could control insect pest on cowpea. We did not know the dangers associated with Karate [a chemical pesticide] which we used before this program. We used to eat on the farm after spraying with Karate; now we know all the dangers and how to handle the chemical. We can now use neem leaves instead."

use are based on their own observations of what works best in their situation. And farmers are also equipped to adopt a knowledge-based approach to other management problems they will face in the future.

A crucial decision farmers need to make is when to intervene with a biological control measure – the control threshold. Because biological control aims to maintain pest populations below damaging levels, simple visible indicators such as crop damage are not usually present by the time the measure needs to be implemented. Instead, farmers must monitor pest and natural enemy populations, and make decisions based on predictions of how these will change if no action is taken.

The scientific basis for farmer decision making in biological control depends on detailed knowledge of pest and natural enemy life histories, crop ecology, and interactions within agro-ecosystems. Developing this knowledge is a goal of IPM research, and translating it into practical tools for farmers is an important outcome. Some tools already exist: for example, a counting tool that allows farmers to monitor numbers of the rice-damaging planthopper and of the spiders that are its natural enemy, and hence the ratio between them, which is used to predict whether the pest population will be held in check or intervention will be needed. More such tools are needed; they are vital to the success of biological control options.

IPM research supports farmers' knowledge and decision making

Farmer participation and learning are at the heart of the IPM approach. By developing a deep understanding of their agro-ecosystem, its biodiversity, and ways to intervene to maintain healthy crops without damaging the ecosystem, farmers are able to make sound decisions that protect their environment and livelihoods. Unlike the 'chemical solution', IPM recognizes that problems are often local and specific, and that the best solution will be one tailored to the individual situation. Armed with the knowledge to do this, farmers and farming communities become empowered to develop sustainable farming systems, as the basis for sustainable and successful livelihoods.

A New Paradigm

Many effective biological alternatives to synthetic chemical pesticides exist for pest and disease vector management, and more are under development. Their advantages over harmful chemical pesticides are clear.

So far, however, the use of biological alternatives has fallen disappointingly short of its potential. Farmers are often not aware of the biological options that exist; if they are, they may still find that these options are not easily available or that they are too expensive. Compared to chemicals, biological alternatives are more complicated to use and the benefits are not always immediately obvious; indeed, many of the benefits do not accrue directly to the farmer but more widely, to the environment off-farm. Farmers sometimes perceive biological options as being less effective than chemicals, because they are expecting the 'quick-kill' results of chemicals.

The private sector has found it difficult to profit from producing and selling biological options in the same way as chemicals. Costs of development and production are generally the same as for chemicals or higher, but because of the specific nature of biological options, markets are usually considerably smaller. It is sometimes difficult to scale up the production of biopesticides and maintain efficacy. And their shorter shelf life, coupled with the need for more stable environmental conditions in storage, make biopesticides more difficult to handle and distribute.

In fact, biological alternatives cannot compete with chemical pesticides when they are evaluated according to the criteria used for the 'chemical model', in which large companies mass produce broad application products that have quick-kill action and need frequent reapplication. Those few that have had some success, notably Bt-based products, owe this to their similarity to chemicals, so that they are accommodated within the chemical model. But most biological options do not fit this model.

Further, this model fails to place value on the characteristics of biological alternatives that make them superior to chemicals: their positive environmental attributes, their specificity, and their ability to reproduce and establish themselves as part of the ecosystem, providing ongoing control. Indeed, in the chemical paradigm, with its emphasis on commercial objectives, these characteristics are often seen as disadvantageous. For example, a broad spectrum of activity is an advantage for a chemical because it increases its potential sales, but pest specificity is an important advantage of biopesticides as it reduces environmental impact. Similarly, the persistence of a biopesticide will reduce the need for future product purchase – a success for farmers, but a failure from a commercial point of view.

Biological options cannot be successful for as long as the chemical paradigm holds sway. What is needed, many believe, is a new paradigm that has farmers, equipped with knowledge tools and biological alternatives, at its center. The vision is one of small-scale, local production of biopesticides, supported by public-sector and farmer participatory research and enabled within appropriate national and international policy environments.

Many of the successful examples of biological alternatives to date have been in developing countries, and it is in these countries that expansion of IPM, IVM and biological alternatives under a new paradigm could have huge benefits for human health and the environment. Further, the new paradigm could allow farmers and rural communities in these countries to benefit from the valuable niche markets opening up in developed countries for 'organically' produced foods. Needed now to support this expansion are:

- Capacity building – for all concerned with crop protection (farmers, researchers, government regulators, private-sector agronomists, local entrepreneurs), training in the relevant aspects of IPM is essential
- Appropriate regulatory frameworks – based on sound science, these will allow biological options to be assessed and monitored for their safety, so that the right products, produced to acceptable standards, can reach the market
- Effective public–private partnerships – which will help develop proven alternatives into commercial products, whether on a local or larger scale.

Governments can support expanded production and use of biological alternatives by, for example:

- Developing a national regulatory framework for biological alternatives
- Supporting research and education in IPM at different levels
- Providing incentives for industry to expand development and production of biological alternatives, for example tax incentives and subsidies
- Promoting the development of small businesses and public–private partnerships
- Developing quality control standards for IPM products, certification systems for commodities produced using IPM, and product labelling requirements that disclose use of pesticides or IPM.

As we strive to move on from 'quick-fix' solutions to more sustainable and holistic options, a concerted effort to spread awareness, build the needed capacity, develop appropriate policy and institutional environments and establish effective partnerships will be needed to launch the new paradigm on which success depends.

Reference Sources and Further Reading

Anon. (2001) Zapping mosquitoes with biopesticides. *Pesticides News* 54: 9. (http://www.pan-uk.org/pestnews/pn54/pn54p9.htm)

Berg H., Kiibus, M. and Kautsky N. (1992) DDT and other insecticides in the Lake Kariba ecosystem. *Ambio* 21: 444–450.

Blanford S., Chan B.H.K., Jenkins N., Sim D., Turner R.J., Read A.F. and Thomas M.B. (2005) Fungal pathogen reduces potential for malaria transmission. *Science* 308: 1638–1641.

Bottrell D.G. (1998) Internationally – where/why biopesticides work. In ESCOP-WGBC Workshop on 'Alternative paradigms for commercializing biological control' (http://www.rci.rutgers.edu/~insects/whitepaper.htm)

CIPC/IPPC/US National IPM Network. Database of microbial biopesticides (http://www.ippc.orst.edu/biocontrol/biopesticides)

Downham M.C.A., Tamò M., Hall D.R., Datinon B., Adetonah S. and Farman D.I. (2004) Developing pheromone traps and lures for *Maruca vitrata* in Benin, West Africa. *Entomologia Experimentalis et Applicata* 110: 151–158.

ESCOP-WGBC (Experiment Station Committee on Policy–Biological Control Working Group) (1998) Alternative paradigms for commercializing biological control. Workshop report (http://www.rci.rutgers.edu/~insects/whitepaper.htm)

FAO (2004) *The state of food and agriculture 2003–2004. Agricultural biotechnology: meeting the needs of the poor?* FAO, Rome.

FAO, UNEP and WHO (May 2004) Childhood pesticide poisoning: Information for advocacy and action. (http://www.who.int/ceh/publications/pestipoison/en/).

Gallagher K.D., Kenmore P.E. and Sogawa K. (1994) Judicial use of insecticides deter planthopper outbreaks and extend the life of resistant varieties in southeast Asian Rice. In R.F. Denno and T.J. Perfect (eds), *Planthoppers, their Ecology and Management*. Chapman and Hall, New York, pp. 599–614.

Integrated Pest Management Resource Centre, http://www.ipmrc.com/

International Biopesticide Consortium for Development website (http://www.biopesticide.org)

IOMC (2002) *Reducing and eliminating the use of persistent organic pesticides. Guidance on alternative strategies for sustainable pest and vector management*. Inter-Organization Programme for the Sound Management of Chemicals, Geneva.

James B., Coulibaly O. and Gbaguidi B. (2003) New solutions for cowpea production in Africa. *Pesticide News* 61: 12–13.

Joung K-B. and Côté J-C. (2000) A review of the environmental impacts of the mibrobial insecticide *Bacillus thuringiensis*. Technical Bulletin No. 29. Hortucultural Research and Development Centre, Canada. (http://res2.agr.ca/stjean/publication/bulletin/bacillus_thuringiensis_e.pdf)

Kelemu S., Cardona C. and Segura G. (2004) Antimicrobial and insecticidal protein isolated from seeds of *Clitoria ternata*, a tropical forage legume. *Plant Physiology and Biochemistry* 42: 867–873.

Langewald J. et al. (1999) Comparison of a synthetic insecticide with a mycoinsecticide for the control of *Oedaleus senegalensis* Krauss (Orthoptera: Acrididae) and other Sahelian Grasshoppers at operational scale. *Biocontrol Science and Technology* 9: 199–214.

Maruca vitrata pheromone trapping in West Africa (http://www.nri.org/maruca/)

Midwest Institute for Biological Control website: http://www.inhs.uiuc.edu/cee/biocontrol/home.html

Neuenschwander P. (2004) Harnessing nature in Africa. Biological control can benefit the pocket, health and the environment. *Nature* 432: 801–802.

Neuenschwander P., Borgemeister C. and Langewald J. (eds) (2003) *Biological Control in IPM Systems in Africa*. CABI Publishing, Wallingford, UK, 414 pp.

Scholte E.-J., Ng'habi K., Kihonda J., Takken W., Paaijmans K., Abdulla S., Killeen G.F. and Knols B.G. (2005) An entomopathogenic fungus for control of adult African malaria mosquitoes. *Science* 308: 1641–1642.

Settle W.H., Ariawan H., Astuti E.T., Cahyana W., Hakim A.L., Hindayana D., Lestari A.S. and Pajarningsih (1996) Managing tropical rice pests through conservation of generalist natural enemies and alternative prey. *Ecology* 77: 1975–1988.

SP-IPM (2005) *Harvesting participation: Farmers as partners in research and learning for integrated pest management*. IPM Research Brief No. 3. SP-IPM Secretariat, International Institute of Tropical Agriculture (IITA), Cotonou, Benin.

Weeden C.R., Shelton A.M., Li Y. and Hoffmann M.P. *Biological control: a guide to natural enemies in North America*. Cornell University (http://www.nysaes.cornell.edu/ent/biocontrol/).

World Bank. *Pest management guidebook* (http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTARD/EXTPESTMGMT/0,,menuPK:584328~pagePK:64168427~piPK:64168435~theSitePK:584320,00.html).

World Health Organization. Pesticides. *Healthy Environments for Children*. Alliance Issue Brief Series (http://www.who.int/heca/infomaterials/pesticides.pdf).

World Health Organization. *Roll Back Malaria Infosheet: Malaria in Africa* (http://www.rollbackmalaria.org/cmc_upload/0/000/015/370/RBMInfosheet_3.pdf).

Photos: Page 4: FAO 22985/I. Baldieri; page 6: IITA; page 9: S. Parrott, Green Ink; pages 10, 11, 15, 17: G. Goergen; pages 12, 22: A. Cherry; page 16: Still Pictures; page 19: A.M. Varela, ICIPE; page 21: D. Djegui.

Writing, editing, design and layout: Green Ink Ltd, UK (www.greenink.co.uk)

Printing: Pragati Offset Pvt. Ltd, India (www.pragati.com)

Front cover (left to right):
Top row: discarded barrels of pesticide (FAO 22981/ I. Baldieri); diamondback moth infected with granulovirus (A. Cherry)
Middle row: predatory mite attacking cassava green mite (G. Goergen); IPM research supports farmers' decision making (A. Cherry)
Bottom row: farmers evaluate biopesticides in field trials D. Djegui); scouting for pests (A. Cherry); diamondback moth (A. Cherry)

SP-IPM members

Asian Vegetable Research and Development Center (AVRDC)
PO Box 42, Shanhua, Tainan 741, Taiwan
Centro Internacional de Agricultura Tropical (CIAT)
AA. 6713, Cali, Colombia
Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT)
Apartado Postal 6-641, 06600 Mexico D.F., Mexico
Centro Internacional de la Papa (CIP)
Apartado 1558, Lima 100, Peru
International Center for Agricultural Research in the Dry Areas (ICARDA)
PO Box 5466, Aleppo, Syria
International Centre of Insect Physiology and Ecology (ICIPE)
PO Box 30772, Nairobi, Kenya
International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)
Patancheru 502 324, Andhra Pradesh, India
International Institute of Tropical Agriculture (IITA)
PMB 5320, Ibadan, Oyo State, Nigeria
International Plant Genetic Resources Institute, International Network
for the Improvement of Banana & Plantain (IPGRI-INIBAP)
Parc Scientifique, Agropolis 2, 34397 Montpellier, Cedex 5, France
International Rice Research Institute (IRRI)
PO Box 933, Manila, The Philippines
West Africa Rice Development Association (WARDA)
01 BP 2551, Bouaké, Côte d'Ivoire
The World Bank, Agriculture and Rural Development, Environmentally
and Socially Sustainable Development Network
1818 H Street N. W., Washington, D.C. 20433, USA
CABI Bioscience
Silwood Park, Buckhurst Road, Ascot, Berkshire, SL5 7TA, UK
FAO Global IPM Facility
Viale delle Terme di Caracalla, 00100 Rome, Italy
BioNET INTERNATIONAL
Bakeham Lane, Egham, Surrey, TW20 9TY, UK
International Association for the Plant Protection Sciences (IAPPS)
NSF Center for IPM,
Box 7553, NCSU, Raleigh, NC 27695-7552, USA
Pesticide Action Network (PAN)-Africa
BP 15938, Dakar-Fann, Senegal
CropLife International
Avenue Louise 143, B-1050 Brussels, Belgium

SP-IPM Secretariat
IITA, 08 BP 0932 Tri Postal, Cotonou, Republic of Benin
www.spipm.cgiar.org

spiPM
for improved livelihoods

FUTURE HARVEST