Use of the Sterile Insect Technique Against Key Insect Pests

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Abstract

The world's population is increasing by ca. 80 million humans per year and in developing countries the total production of food must be doubled within the next thirty years. Expansion of arable land can only play a minor role to further growth in food production, but attaining substantial increases in average yields will become increasingly difficult, and will have to focus on using resources more efficiently. Pre-harvest losses in developing countries are estimated at about 40%, while post-harvest losses add a further 10-20%, much of which is due to insect pests. There could hardly be a less efficient use of resources than to invest water, fertiliser, seeds, land, time, effort and money in producing food, only to have it partially or totally destroyed by insects or other pests. Consequently, an important strategic component of raising productivity and assuring global food security will increasingly be investment in improved insect pest management, one method of which is the Sterile Insect Technique (SIT).

Overview - Problems and Rationale

The World Bank predicts an increase in insect pests, including disease vectors, due to increased international trade and global climatic change. Examples of these trends are already apparent in the livestock sector, as tsetse flies and Old World Screwworm (OWS) are advancing into previously uninfested agricultural areas.

The present value and importance of conventional synthetic insecticides to pest control cannot be questioned. World pesticide consumption is growing at ca. 5% a year, but there are major resistance problems, as well as increasing public awareness of the high toxicity, residues in food, contamination of water and the environment, and concerns of human health effects. The consequences of wide-spread application of broad-spectrum insecticides have been outbreaks of secondary pests that result in additional crop losses and insecticide use because of the inadvertent destruction of natural enemies as well as the impact on beneficial non-target insects such as honey bees and other pollinators, and the killing of fish, birds, mammals and other wildlife.

In view of the above there is an urgent need to develop and implement more environment-friendly methods to manage insect pests, such as the Sterile Insect Technique (SIT), that are biologically-based and therefore are more sustainable. Losses in production and trade in crops and livestock products due to major insect pests, coupled with rising concerns about food safety and quality and biodiversity, have led to demands at national and international levels for the development and introduction of area-wide and biological approaches for the integrated management of major insect pests. Many countries have benefited from insect pest intervention programmes which, through the integrated use of SIT, incorporate these concepts. Apart from reducing crop losses and pesticide use, a major aim of appropriate pest insect intervention is to facilitate international trade of agricultural commodities by providing Member States with better options for addressing technical barriers to trade and other sanitary and phytosanitary issues brought before the WTO. Area-wide use of SIT has been shown successfully to establish pest free areas, areas of low pest prevalence through a systems approach, and can be used to a greater degree in the future to achieve more effective management of insect pests.

Current Status and Achievements

The principle of SIT and its advantages

The Sterile Insect Technique (SIT) involves mass production of the target insect pest species, sterilisation and releasing into the field on a sustained basis and in sufficient numbers to achieve appropriate overflooding ratios. Sterile males find and mate with fertile females, transferring infertile sperm. There are no resulting viable offspring, resulting in a reduction in the natural pest population.

Unlike non-selective insecticide-based control, the SIT and other less known genetic pest control methods are environmentally friendly. The induced sterility is directed exclusively at the target species and, contrary to other biological control methods, no adverse impacts on non-target organisms have been reported. It can be integrated with other conventional and biological methods, such as parasitoids, predators and insect pathogens (biopesticides). This integration enables the application of totally biological systems for managing some of the world's most important insect pests.

SIT also exhibits increased efficiency with decreasing target population density. As a result it is the only environmentally friendly technology available that can eradicate insect pests if applied consistently on an area-

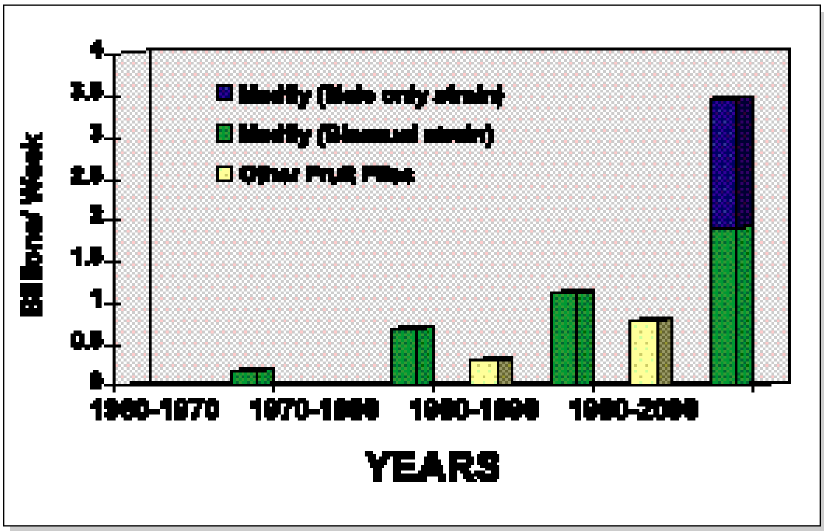

Figure 1
Worldwide production capacity of sterile fruit flies

wide basis. This area-wide population management approach is central to the application of SIT. It involves action against the total population of the pest over a period of generations, requiring much less input and achieving much greater suppression than a higher level of suppression on most, but not all, of the population in each generation.

PRACTICAL APPLICATION OF SIT IN THE PAST

Screwworm flies

The first and probably most widely known application of the SIT against a major insect pest is the successful screwworm programme that eradicated this pest from large areas of North and Central America. The New World Screwworm (NWS), *Cochliomyia hominivorax*, a myiasis-causing fly in warm-blooded animals, including humans, is a pest of major economic importance in agricultural systems with extensive livestock production or with increasing labour costs.

After a successful SIT pilot eradication in Curazao in 1954, a successful eradication programme was carried out in Florida in the late 1950s. This was followed by total eradication of NWS from the United States between 1966 and 1982. A production plant with a capacity to produce 600 million sterile flies per week was opened in southern Mexico in 1976. Eradication in Mexico moved progressively southward to the Isthmus of Tehuantepec by 1984, and all of Mexico was declared free of NWS in 1991. Since then eradication has been achieved in Belize and Guatemala in1994, El Salvador in 1995, Honduras in 1996, and recently Nicaragua (1999). Sterile fly releases are presently continuing over Costa Rica, which is already largely NWS-free, and over Panama, where a new mass rearing facility is foreseen to maintain a permanent barrier of sterile flies in the Darien Gap between the Panama Canal and the border with Colombia.

The accidental introduction of NWS into Libya in 1988 represented a major emergency in view of the threat it represented to wildlife and livestock not only for Libya, but for the entire North Africa and Mediterranean regions. It was the first time that this destructive insect became established outside its natural range in the Americas, and if left uncontrolled it would inevitably spread to neighbouring countries and eventually into the Near East, Mediterranean Europe and possibly even Sub-Saharan Africa. By 1990 the infestation had spread to 25,000 km^2 containing some 2 million livestock. A decision was taken to try to eradicate the outbreak using sterile insects and an internationally funded programme was initiated. Sterile pupae were transported from Mexico to Libya and released by air as adult flies over a treatment area of 40,000 km^2. Between 1990 and 1992, 1,300 million sterile flies were released and 40 million animal inspections were carried out, resulting in the eradication of NWS. The last case of screwworm was reported in 1991.

Fruit flies

Fruit flies seriously interfere with the international marketing of fruit and vegetable commodities, and thus are a major impediment to economic development. Few insects have a greater impact on world trade in agricultural produce than fruit flies, and SIT is seen as a major tool within a systems approach to create internationally recognised fly free or low prevalence areas to overcome these trade barriers. Fruit flies also cause devastating direct losses requiring intensive insecticide treatments to produce worm-free fruit. The resulting damage to non-target beneficial organisms, disruption of biologically based controls of other orchard pests, and general contamination of the environment, are the other major forces driving the need for more environment-friendly methods such as SIT to control fruit flies.

The Mediterranean fruit fly (medfly), *Ceratitis capitata*, a notorious quarantine pest because of the extremely wide range of host it attacks, has been one of the main targets for SIT. The first large SIT programme against medfly was initiated in Mexico in 1977, with the construction of a 500 million sterile fly mass rearing facility. The aim of the programme was to prevent the spread of medfly, which had become established in Central America, into Mexico and the USA, which threatened Mexico's multi-million fruit and vegetable export trade with the USA. The programme succeeded in 1982 in eradicating medfly from areas it had already infested in southern Mexico and has since then maintained a sterile fly barrier from southern Belize through Guatemala to southern Mexico to assure the fly-free status of Mexico, USA and half of Guatemala.

This was the starting point for similar medfly control or eradication programmes in various other parts of the world such as Chile, Argentina and Peru. Repeated medfly introductions into California and Florida, threatening the exports of a multi-billion fruit industry, have required recurrent emergency eradication actions, costing annually millions of US dollars. In view of the public opposition to aerial bait-spraying, often over urban areas, and the failure to eradicate these outbreaks with insecticides, authorities successfully embarked on the area-wide use of SIT over the whole Los Angeles Basin starting in 1994, involving the aerial release of over 300 million sterile flies per week. The SIT strategy was so successful politically and environmentally, but also from the economic point of view (costing on average less than half compared to the recurrent emergency programmes), that after successful eradication in 1996, area-wide aerial releases were continued on a permanent basis over high risk areas in the Los Angeles basin. This preventive or prophylactic approach has stopped any major outbreaks of medfly.

Recent development by IAEA of male-only strains (Figure 1), opening the possibility of using SIT for routine medfly control rather than eradication, has resulted in SIT programmes in various stages of development in Madeira, Israel, Jordan and Palestine, as well as South Africa, and feasibility studies in various other Mediterranean countries. This considerable activity indicates an increasing interest in the region in substituting medfly control based on insecticide sprays with environment – friendly medfly control based on SIT. The economic feasibility of this approach has been confirmed by a number of benefit-cost analyses.

For medfly and other fruit flies, the current worldwide weekly production capacity of sterile flies has now reached several billion sterile flies.

Bactrocera and *Anastrepha* are also devastating fruit fly pests of economic and quarantine importance. Great advances have been made in developing sterile insect technology for some of these species. The melon fly programme in southern Japan culminated in the mid-1990s in the eradication of this species from all islands of the Okinawa and other archipelagos. In Australia, SIT was successfully applied to eradicate the Queensland fruit - fly from Western Australia, and preventive SIT releases are being used in Southern Australia to protect fruit growing areas from the seasonal movement of the pest into commercial areas. In the Philippines the sterile insect technology has been adapted to *B. philippinensis* and a pilot programme has been in progress in mango-producing Guimaras Island.

There has been an operational SIT programme in the USA as a quarantine against the Mexican fruit fly along the border with Mexico since 1964, and SIT is being used in Florida against *A. suspensa*, in combination with parasitoids and other methods, to establish fly – free zones in areas of citrus production. In northern Mexico a large SIT programme against various *Anastrepha* species, funded by the fruit industry and federal and state governments has been in progress since the early 1990s with the objective of developing fly – free areas.

Tsetse Fly

Tsetse flies have a devastating effect on humans and livestock production in 38 countries south of the Sahara covering ca. 7-11 million km^2. Trypanosomiasis, caused by tsetse, represents a key impediment to the establishment of sustainable agricultural systems in many areas of great agricultural potential. People in Sub-Saharan Africa get a third or less than a third as many calories and half as much protein from animal products as people in developed countries. Also, no healthy cattle are available in tsetse infested areas for ploughing and as draught animals, thus effectively preventing economic development in many countries south of the Sahara.

Sufficient food can only be provided if existing but unproductive crop and livestock systems continue expanding into wildlife areas or if more intensified and better integrated systems are introduced into existing areas. The latter is necessary for preserving natural resources but will require, amongst others, the introduction of improved livestock breeds which can only be maintained profitably if area-wide approaches are applied to address the tsetse/trypanosomiasis problem, and preferably if tsetse flies are eradicated through integrated interventions.

To date, no major break-through has been made in removing or sustainably controlling the threat of tsetse and trypanosomiasis. Present disease control, mainly based on trypanocides, insecticide impregnated targets, or even habitat destruction and game elimination, is unsatisfactory in the long term due to high cost, resistance and environmental concerns. The transboundary nature of the disease requires that eventually an area-wide integrated approach must be designed for entire sub-regions to break the vicious cycle of human/livestock diseases and economic disadvantage.

Recent breakthroughs in mass rearing and aerial release technology have culminated in the first area-wide and integrated use of SIT to eradicate tsetse in Zanzibar, initiated in 1994 against *Glossina austeni*. Intensive monitoring over Zanzibar during the three years following eradication shows no tsetse have been found. Disease monitoring also has shown that cattle are free of trypanosomes.

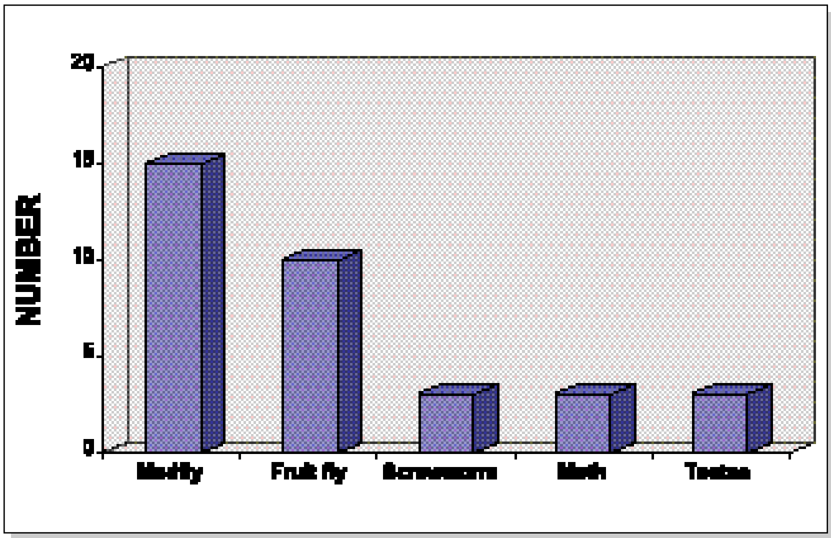

Figure 2
Worldwide facilities for mass production of sterile insects

Lepidoptera

Lepidoptera (moths) are amongst the most damaging pests of food and fibre crops, forests and stored products throughout the world. Some of these pests are also major candidates for inherited sterility programmes. Currently, most of these species are controlled largely by applications of insecticides, but in many instances this practice has induced insecticide resistance and secondary pests outbreaks.

The cotton pink bollworm, *Pectinophora gossypiella*, is a serious cotton pest in many parts of the world. A programme against this pest in California has since 1968 been successfully integrating aerial sterile moth releases and various cultural and other controls. Its objective has been to prevent this migrating pest from becoming established in the San Joaquin Valley, to protect the cotton grown there. In order to address moth migration at its origin in other cotton growing areas, the Phoenix, Arizona, mass rearing facility was enlarged in 1994 and the programme was extended to the Imperial Valley and in 1998 to other valleys to eradicate the established pest in these areas. Plans exist to include all cotton areas in other southwestern states, Arizona and New Mexico in the USA and Baja California Norte and Sonora in Mexico.

Codling moth, *Cydia pomonella*, is a key pest of apples and pears in many temperate regions of the world, being the target of intensive insecticide sprays. An SIT programme against this pest was initiated in British Columbia, Canada, in the early 1990s. With funding from the federal and provincial governments, a mass rearing facility was built with a capacity of producing 15 million moths per week. After four years of operations, the programme has been successful in controlling the pest with growers essentially reporting no damage and most not having to spray against codling moth, allowing the production of organic fruit.

Current SIT fly factories

The numbers of existing sterile insect mass production facilities for the major insect groups for which SIT is being applied is shown in Figure 2, where it can be seen that

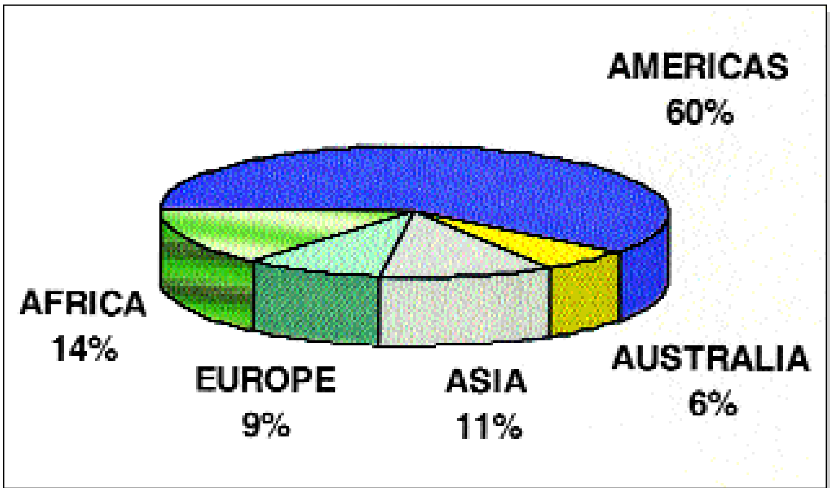

Figure 3
Sterile insect mass production facilities

medfly and other fruit fly SIT are the most widely adopted.

The worldwide distribution of these facilities, shown in Figure 3, indicates that 60% of these SIT facilities are located in the Western Hemisphere, where application of SIT technology is most advanced.

ECONOMIC AND ENVIRONMENTAL BENEFITS

Economic analyses have shown that SIT applied for control or for eradication as part of an integrated approach is competitive with conventional methods when considered over longer time frames. Particularly in the case of eradication, the impact of control or eradication efforts using this technique are concrete and directly measurable. Even when excluding the large environmental benefits that have resulted from the implementation of SIT control or eradication programmes, SIT has had major economic impacts.

In the case of the New World Screwworm fly, the investment of almost US$ 1000 million between 1957 and 2000 resulted in the eradication of the pest from the northern half of the whole Western Hemisphere. The annual direct producer benefits in the previously affected countries is estimated at US$ 1165 million and economists estimate that the multiplier effect on the economy and wildlife health component is at least three times this amount.

For fruit flies, eradication of medfly from Mexico and maintaining the country free of this pest at an annual cost of US$ 8 million, has protected fruit and vegetable export markets of close to US$ 1 billion/year. The eradication of the medfly Mediterranean fruit fly from Chile, is estimated to eventually result in opened markets for fruit exports of up to US$ 500 million per year. Allowing the establishment of medfly in California would result in the loss of $US 1 billion a year and result in a drastic increase of insecticide use. In Israel, recent efforts to use SIT for control, rather than eradication of medfly, have already resulted in annual exports of peppers and tomatoes to lucrative markets in the United States valued at US$ 5 million.

The elimination of the trypanosomiasis problem on Zanzibar is resulting in significant gains in the livestock sector with the introduction of more productive cattle breeds. Whereas in 1985/86 only every third farming household had cattle, in 1999 four out of five farmers are integrating farming and cattle management. Already more than one third of the total milk production on Zanzibar originates from improved cattle breeds, although these improved breeds only represent about 5% of the total cattle on the island.

The development of a new synthetic insecticide currently takes an average of 10 years to bring a new product to market at an average cost of ca. US$ 120 million. Development of an SIT package for a specific key pest, involving mass rearing and aerial release, as well as field monitoring and suppression system, requires much less funding. The cost of insecticide development will probably continue to rise because of increasingly stringent standards imposed by regulatory agencies, and will be reflected in more expensive newer insecticides, resulting increasingly in more competitive costs for biologically-based methods such as SIT.

In general, the economic feasibility of non-chemical pest control tools, including biologically-based methods such as SIT, will become increasingly apparent, with more realistic accounting of the negative environmental effects of synthetic pesticide applications, and further improvement in the cost-effectiveness of these methods as a result of continuing investment in applied R & D.

FUTURE TRENDS IN THE USE OF SIT

The vast majority of insect species are beneficial to man. Of the estimated several million insect species, only a few thousand are pests of man, livestock, food or fibre crops, or stored products. Out of these insect pests, a majority are occasional, surpassing the economic threshold level only occasionally when favoured by special weather conditions, or secondary pests, when the action of their enemies is disrupted by human intervention. For these pest species the conventional IPM approach has been successful.

For the so-called key insect pests, however, which continuously cause damage above economic threshold levels, this IPM approach has not been so effective in view of increasing pesticide consumption. Considering the importance of these key pests and their potential for economic and environmental impact, these are the species that are the targets for area-wide approaches including in some cases the use of Sterile Insect Technique (SIT). Among key pests, obviously only those species should be considered as targets for which there are no promising alternative technologies under development.

The applicability of area-wide techniques will be strongly encouraged by global economic trends. Farmers and growers are being forced towards further rationalising and integrating of activities, as well as associating into large production and trading units, whose survival will often depend on overcoming pest-related non-tariff barriers to the free trade of their agricultural products.

Screwworm flies

In the short term, support to SIT eradication projects is focusing on the Caribbean islands where the pest is still endemic, making it a possible source of re-infestation. In 1998, a NWS eradication project was initiated in Jamaica, where aerial sterile fly releases are currently under way throughout the island. Eradication of NWS is expected by the year 2001. Preparatory activities are also already in progress to initiate NWS eradication projects, first in Cuba, and in the medium term in Hispaniola (Dominican Republic and Haiti). In the long term, NWS eradication can be envisioned for South America, where there is interest in several countries for such a large programme.

The Old World Screwworm (OWS), *Chrysomya bezziana*, is another obligate parasite of warm-blooded animals that is confined to tropical and sub-tropical regions of the Old World, where it makes large scale beef production uneconomic. Australia is free of OWS but establishment of this pest is a permanent threat to Australia's large livestock industry and scientists there have successfully adapted the existing NWS technology for OWS. There is demand for this technology in islands of Southeast Asia and particularly in the Middle East, where OWS has spread over the last decade throughout the Persian Gulf region. It is now causing large outbreaks in Iraq, and from there it is threatening to invade the Near East and Mediterranean regions. Feasibility studies are in progress for the eradication of OWS from selected regions in the Middle East and South East Asia.

Fruit flies

There is much interest in applying SIT against other fruit flies and in other regions. The European Union, which until recently was not interested in supporting the application of the SIT for medfly control or eradication, is increasingly realising the obvious advantages of the technique in terms of economics, environment and consumer protection. As a result the EU recently requested support from IAEA and FAO for an SIT initiative and is currently encouraging the establishment of fruit fly SIT control rather than eradication programmes among its members in Southern Europe. Currently there is also much interest in various Central American and South American countries for regional efforts to expand areas under SIT and for developing SIT technology for various other *Anastrepha* fruit flies.

Tsetse flies

The recent success in Zanzibar has led to its consideration for areas of mainland Africa. Eradication of tsetse in areas with high land-use pressure is the favoured option for governments, seeing that it creates the prerequisite for introducing intensified livestock/agricultural practices, thereby limiting the need for expanding lower-productive land-use systems into wildlife areas. Thus considerable efforts are under way to upgrade tsetse SIT for integration into intervention campaigns in selected areas of mainland Africa. This requires that methods be developed which produce at least 500,000 sterile males per week for release over areas of 5,000 – 10,000 km^2.

A recent DFID funded economic assessment of the tsetse/trypanosomiasis problem concludes that investments into larger scale eradication programmes will result in 2.6-fold benefits of investments over a 20 year period, accumulating to more than fivefold the investments in subsequent years. In this context tsetse SIT is receiving increasing attention and support, as it is highly environmentally friendly and, in many situations, is an ideal complementary tool to conventional tsetse intervention methods.

The Ethiopian government has embarked since 1996 on preparatory activities for an SIT programme for eradicating tsetse flies from 25,000 km^2 of the Southern Rift Valley. The first phase consisting of baseline data collection will soon be completed, and so far *G. pallidipes* was identified as the only tsetse species in the core area of the surveyed Rift Valley. Efforts are also being pursued to establish a mass reared strain of *G. pallidipes* originating from the area, and construction of a mass rearing facility with a capacity to produce 1 million sterile males is scheduled to be initiated in 2000. The Tanzanian government has identified two other sites in Tanzania where similar projects would have an equally good chance of success. Tsetse SIT eradication projects are currently also being considered or are in preparation in selected areas in Kenya, Mali, South Africa and Botswana.

Lepidoptera

A number of other developments are in progress for applying SIT for control purposes against moth pests in various parts of the world but these are mostly experimental and will require considerable additional research or upscaling to become operational. These include codling moth in South America and South Africa, gypsy moth in the USA, diamondback moth in Mauritius, date moth in Tunisia, cotton bollworms in China and Pakistan and a number of other countries, sugarcane borer in Cuba, peach borer in Bulgaria, etc.

CONCLUSION

Insect pest control is becoming more difficult. The intensification of cropping, reduced crop rotations and increased monocultures will create further biological imbalances of the agricultural environment. Future pest control will have to be conducted without further impairing biological diversity and degrading the environment, and will have to be accomplished to a significant extent with less reliance on pesticides. The environment will be further disrupted as a result of the continuing expansion of world-wide travel, tourism, as well as trade in agricultural products, increasing the introductions of noxious plants, insects and other pest organisms from one area to another. Furthermore, insecticide use, as well as insect damage levels considered acceptable in the past, are now no longer acceptable, and millions of people and animals suffer from arthropod-borne diseases that are increasing in importance due to resistance.

In view of the above, there is no doubt that the demand for SIT and related biologically-based insect pest control techniques that can address transboundary pest problems will continue to increase. The close collaboration of IAEA and FAO over the past four decades is succeeding in developing and implementing SIT as an effective tool within an integrated approach to pest management.

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