Balancing the need for pesticides with the risk to human health

Gilles Forget

Health Sciences Division,
International Development Research Centre,
Ottawa, Ontario, Canada

Pesticides have been used successfully in the control of a number of diseases such as typhus and malaria. It is more difficult to assess the benefits of pesticides in agricultural practice because their introduction has often coincided with that of chemical fertilizers and resistant crop varieties. The development of resistance by target organisms is now eroding past successes. Farmers and public-health workers must often apply increasing concentrations of pesticides, thereby increasing the risks of occupational and accidental intoxications. New compounds are developed that, although often safer to users and to the environment, can be considerably more costly. Surveys conducted in the tropics suggest that a large proportion of noncriminal, nonsuicidal incidents of pesticide poisoning is due to lack of knowledge and unsafe practices in the storage, handling, and spraying of these chemicals. Concern is growing that cases of poisoning and death could be grossly underreported because of lack of diagnostic expertise on the part of treating health practitioners. The key to the future appears to lie not in discarding pesticides but in their integration into sound pest-management practices: proper training of users, continued development of environmentally safer compounds, initiation and maintenance of sound storage and transport practices, and integrated pest management, such as intercropping and biological control.

Pesticides are used worldwide to control pests that destroy crops and transmit diseases to people and animals. Developing countries are steadily increasing their demand for imported chemicals, many of which are used in agriculture. Between 1970 and 1980, the value of pesticide purchases in Third World countries increased 6.5-fold in constant dollars (World Resources Institute 1986).

Although pesticides are used both in agricultural and public-health programs, the methods differ and the parameters for assessing their efficacy or cost-effectiveness vary greatly. However, the development of pest resistance to pesticides and their effects on nontarget organisms, including humans, have a similar impact and are of equal significance. Moreover, the use of pesticides in one sector effects the other. It has been surmised that large-scale spraying of dichlorodiphenyltrichloroethane (DDT) on cotton in Central America was responsible for the development of resistance to the pesticide in *Anopheles* spp., which are malaria vectors (Chapin and Wasserstrom 1981).

In the past, pesticides have been very successful in controlling and eradicating several diseases from endemic areas. Regretfully, these past successes in health are now being eroded because of the appearance of resistant vectors. Similarly, although agricultural experiments have demonstrated the benefits of pesticides for crop protection, the complexity of intervening factors has made it difficult to measure their real impact on world agricultural production.

The use of toxic chemicals is fraught with risks both to users and to the environment in which they are released. The number of reports of human poisonings and mortality due to pesticides is growing (Foo 1985), although it is not clear whether this represents a rising trend or better reporting because of increased awareness. Nevertheless, pesticides will remain a necessary part of our arsenal for crop protection and disease prevention. In this paper, issues related to their efficacious and safe use are reviewed.

Uses of pesticides

Public health

As Metcalf (1970) wrote, "There are many examples of insect pests and of vector-borne diseases that were never controlled successfully until the advent of modern insecticides." The first documented instance of disease control by pesticides was that of typhus accomplished by the large-scale delousing of people in Algiers in 1943 and Naples in 1944 using DDT (Metcalf 1970). Residual spraying with DDT was also responsible for the eradication of malaria on the island of Sardinia in the 1940s (Metcalf 1970). Since 1950, there has been no evidence of malaria transmission on the island.

Considerable success was also obtained in India where a malaria-control program was launched in 1953. Total reported cases were reduced from 75 million annually in 1947 to 100 000 in 1965, while number of deaths due to malaria dropped from 800 000 per year to none (Reuben 1989). In Sri Lanka, similar results were achieved. The crude death rate fell from 25 per 1 000 in 1921 to 8 per 1 000 in 1971; 23% of the decrease is believed to be due to the reduced incidence of malaria (Ault 1989). Deaths from malaria were reduced by 36% the year immediately after the inception of residual DDT spraying in 1935 (Metcalf 1970).

Another example of successful disease control by pesticides is the onchocerciasis control program carried out by the World Health Organization (WHO) in West Africa. In 1970, an estimated 20 million people in the region suffered from onchocerciasis (Metcalf 1970). In the seven West African countries where the program was implemented, it was believed that 1.5 million people harboured the parasite, which caused severe vision impairment or blindness in 70 thousand of them. For example, in Burkina Faso, 400 000 of the 4.5 million inhabitants were affected by onchocerciasis (Remme and Zongo 1989). The onchocerciasis control program was launched in 1974, by killing larvae with temephos, an organophosphate insecticide. After 12 years, only 9 new cases were reported from 184 indicator villages, compared with the expected 800, and the microfilarial load had declined by 95%. The program is considered a success by many (LeBaerre et al. 1989).

A major setback in the use of pesticides for public health has been the development of resistance in many disease vectors. For example, body lice, which are vectors for typhus, are now resistant to DDT and other organochlorine insecticides such as lindane and to organophosphates such as malathion (PAHO/WHO 1973). The development of insecticide resistance is escalating. The number of resistant arthropods grew from 2 in 1946 to 150 in 1980, while resistant mosquito species, which numbered 7 in 1957, rose to 93 in 1980 (WHO 1984). This has had severe consequences for malaria-eradication programs. Although resistance was observed in the course of the onchocerciasis-control program, rotation of five insecticides and application of mixtures allowed for efficient management of this problem (WHO 1982).

Social resistance to the use of pesticides has also hampered their usefulness. Often residual spraying in homes for malaria control is less popular when people acquire better living quarters (Reuben 1989). Notwithstanding these problems, the consensus is that chemical pesticides will probably continue to be the principal component of most vector-control programs, at least in the foreseeable future (WHO 1988).

Agriculture

Assessing the benefits of pesticides in agriculture is difficult, partly because their introduction (Table 1) has often coincided with the use of fertilizers, mechanization, and high-yield crop varieties. For example, between 1952 and 1968 pesticide use in the United States increased by 269%, fertilizers by 292%, and machinery by 130%, while agricultural labour was reduced to 53% (Carlson and Castle 1972).

Although it has been established that pesticides kill pests, there is controversy surrounding their efficacy in actually increasing world food production. Field trials in the USA showed substantially increased production in test plots

Table 1. Introduction of pesticides in the tropics for common agricultural use.

Family	Year of introduction
Organochlorines	1940
Organophosphates	1960
Herbicides	1960
Carbamates	1970
Pyrethroids	1975
Bacillus thuringiensis	1980

Source: World Resources (1986).

treated with fungicides compared with control plots (Zweig and Aspelin 1983). The use of pesticides can increase rice yield by 50% compared to an untreated test plot (Zweig and Aspelin 1983), and treating tomatoes with pesticides increased production by 141% compared with untreated plants (Decker 1974). Similar treatment with fertilizers alone increased the yield by 181%, while combining fertilizers with pesticides increased the yield by 253% (McNews 1967).

The common wisdom is that pests (insects, weeds, and pathogens) are responsible for a loss of one-third of preharvest yields (Cramer 1967). Surprisingly, this ratio changed little between 1942–45 (31.4%) and 1974 (33.0%) when pesticide use was common (Fig. 1). In fact, losses due to insects increased steadily from 7.1% to 13.0% during this period. The loss of cotton crops to insects increased from 10% in 1900 to 19% in the 1950s. For maize, the loss increased from 8% to 12% over the same period (Plucknett and Smith 1986). In 1986, the percentage of all US crops lost to insects was twice that of 1940 (Metcalf 1980). This has led many to conclude that crop damage from insect infestation has not decreased as a result of pesticide usage, at least in the USA, and that it has actually increased (Pimentel 1976; Odhiambo 1984; Plucknett and Smith 1986).

Overall, pesticides have had a positive effect on crop yields that is not offset by the poor record of certain insecticides. Herbicides, for example, have become central to many types of agriculture and their use has been instrumental in decreasing preharvest losses in the USA from 13.8% in 1942–51 to 8% in 1974 (Cramer 1967). Headly (1968) estimated that each additional $1 spent on pesticides in 1968 would increase the value of protected crops by $4. However, he stressed that these values were based on field trials and did not account for geographic, climatic, and other real-life variables such as variations in pest infestations.

Modern, high-yield cultivars depend on higher levels of inputs that must be applied at the right time. However, the monocultures that are now the mainstay of world agricultural production have made this system unstable. This may explain why the use of pesticides has not increased world food production to the levels predicted in experimental trials.

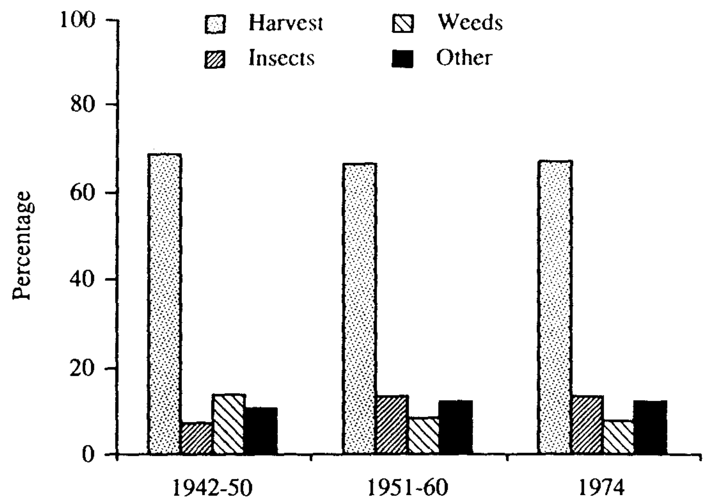

Fig. 1. Preharvest yields and losses to insects, weeds, and other causes, over the period when insecticides became widely used (Pimentel 1976).

Intoxication, morbidity, and mortality

Acute poisoning

Pesticides are toxic chemicals by design and, as such, they represent risks to users. In developing countries, where users are often illiterate, ill-trained, and do not possess appropriate protective equipment, the risks are magnified. Furthermore, comprehensive bodies of legislation to regulate the use and distribution of pesticides often do not yet exist. When legislation is enacted, it is often difficult to enforce given existing structures and budgets. For these reasons, nonoccupational poisonings constitute an important public-health problem in the Third World.

From first suggesting in 1972 that 500 000 cases of pesticide poisoning were occurring annually, WHO has now increased its estimate to 1 million annual poisonings with 20 000 resulting in death (WHO 1986). These estimates were based on area mortality reports submitted to WHO, area morbidity surveys, national mortality statistics for accidental pesticide poisoning as reported to WHO, and preliminary analyses of mortality statistics for accidental pesticide poisoning as reported to WHO. Estimates vary from 1 111 000 cases per year reported in area mortality reports to 834 000 cases determined through analysis of mortality statistics for accidental poisoning reported to WHO. Death estimates range from 20 000 in area mortality reports to 3 000 recorded from mortality statistics for accidental poisoning. The actual figures may be much higher (Chapin and Wasserstrom 1981) as estimates have fluctuated widely.

The first large-scale survey of pesticide poisoning was carried out by WHO in Sri Lanka (Jeyaratnam et al. 1982). The results revealed the seriousness of the problem. The International Development Research Centre (IDRC) funded a similar survey in Indonesia, Malaysia, Sri Lanka, and Thailand in 1983 (Jeyaratnam et al. 1986). Again, the results confirmed the significance of pesticide poisoning in Asia (Table 2). Professor Jeyaratnam presents an updated account of these results and the conditions in several Asia countries and the need for a common research agenda are described by Dr Lum and his colleagues in this volume.

A more recent survey conducted in Sri Lanka by the National Poison Information Centre (NPIC) indicated that, in 1986, 47.3% of all poisonings for which victims were admitted to state hospitals were due to pesticides, principally acetylcholinesterase inhibitors (Fernando 1990). Of these, 10.1% (1 452) resulted in death. These figures do not include another estimated 1 500–2 000 deaths by poisoning from all causes that were never reported to hospitals (Fernando, this volume). In this volume, the results of research conducted in several developing countries are presented (Liesivuori, Sansur et al., Condarco et al., and Castaneda) and reveal the seriousness of the problem in these countries.

Clearly, all these cases of poisoning were not occupational. In the first Sri Lankan study, the investigators reported that a large proportion (73%) of cases were suicidal in nature (Jeyaratnam et al. 1982). Using the NPIC registry, Fernando (1990) reported that 53% of all inquiries about poisonings were related to self-inflicted incidents. In Latin America, however, it appears that most cases of pesticide poisoning may be occupational. In Costa Rica, for example, 67.8% were work-related compared with 6.4% that were suicidal (PAHO 1986).

Herbicides are not highly toxic, but surprisingly they are responsible for many cases of poisoning. Paraquat, in particular, is implicated in many cases of poisoning in developing countries. In Fiji, Papua New Guinea, and Western Samoa, for example, it is responsible for the majority of human poisonings (Mowbray 1986). In Malaysia, Mahatevan (1987) reported that out of 569

Table 2. Extent of pesticide poisoning in Indonesia, Malaysia, Sri Lanka, and Thailand.

	Agricultural workers (%)[a]	
Country	Ever poisoned	With AChE between 50 and 75%
Malaysia	13.3 (4 351)	37.4 (821)
Thailand	8.1 (4 971)	45.7 (318)
Sri Lanka	4.6 (3 439)	17.2 (144)
Indonesia	4.1 (1 192)	1.5 (99)

Source: Jeyaratnam et al. (1986, 1987).
Note: AChE = acetylcholinesterase.
[a] Sample size is given in parentheses.

deaths caused by pesticide poisoning, 310 were due to this herbicide. In Colombia, Dr Arroyave conducted an epidemiological survey of paraquat poisoning (Arroyave, this volume).

Loevinsohn (1987) reported a 27% higher nontraumatic mortality rate in rural men compared with an urban population. The increase was ascribed mainly to cardiovascular and cerebrovascular incidents that may be confused with symptoms of poisoning by organochlorides. Such misdiagnoses are not unlikely in rural, primary health-care settings of the Third World. Loevinsohn has convincingly argued for an association between this high mortality rate and pesticide poisoning.

Even pesticides that are purported to be relatively safe for humans can cause health problems when mishandled. Severe intoxications have been associated with pyrethroid insecticides in China (He et al. 1988; He et al., this volume).

In the pesticide formulating and packaging industry of Egypt, Amr and his coworkers found an astounding number of workers suffering from pesticide-induced symptoms. This work may well serve as a model for more studies in the pesticide-manufacturing process in developing countries (Amr et al., this volume).

Chronic and long-term effects

Use of many organochloride chemicals has been restricted because of their long half-life in the environment. Their persistence causes even small amounts to become concentrated in the food chain to toxic levels. Although most organochloride insecticides are no longer used in many developed countries, their low cost makes them attractive, especially for public-health applications, in developing countries. DDT remains the chemical of choice for many vector-control programs, such as those for malaria and leishmaniasis, and it is still used to eradicate fleas and lice as a control measure against typhus and plague.

Organochlorine residues have been reported in various foodstuffs in developing countries: red meat, poultry, game, and vegetables in Nigeria (Atuma 1985), eggs in Kenya (Mugambi et al. 1989), and potatoes in Egypt (El Lakwah et al. 1989). Organochlorine residues are also found repeatedly in human milk (for an excellent review, see Jensen 1983) in all parts of the world, including countries where they have been banned for many years. Levels measured in Third World countries suggest that nursing infants are often ingesting residues at levels many times greater than the acceptable daily intakes proposed by the Food and Agriculture Organization (FAO/WHO 1988).

Many organochlorinated pesticides have now been banned from all but a few public-health uses, because their resistance to environmental degradation would allow them to accumulate with dire consequences to the biota. This volume would have been incomplete without some discussion of the effects of pesticides on nontarget organisms. Drs Mineau and Keith have studied the impact of pesticides on Canadian wildlife; their paper will be of considerable interest to all who care for the conservation of nature.

The molecular mode of action of organophosphates and carbamates (acetyl-cholinesterase inhibitors) may help explain why they are the cause of most pesticide intoxication reported. The effects of acute poisoning are rapidly felt by the victim, and quickly lead him or her to seek health care. However, several delayed effects of organophosphate intoxication have now been described (Senanayake and Johnson 1982) and their full significance has not yet been established in relation to community health.

Acetylcholinesterase inhibitors may pose a greater risk to human health in the Third World where hunger is often a daily reality. Laboratory studies have shown that the hepatic enzyme activity of animals suffering from protein deficiency was more susceptible to the administration of malathion than that of well-fed animals (Bulusu and Chakravarty 1984). The compound also caused a decrease in liver protein and lipids in these animals. The significance of such findings to public health has yet to be evaluated.

Causes of pesticide intoxication

Many surveys of pesticide poisonings identify lack of knowledge and improper practices on the part of handlers as key factors in most cases of intoxication. This holds true for occupational accidents as well as for accidental poisonings in the home or elsewhere. Drs Condarco (Bolivia), Rubin de Celis (Peru), Mwanthi (Kenya), and Sansur (Jordan) describe their work on this subject in this volume. Dr Condarco's study was concerned with the practices of farmers using pesticides in the three distinct ecological zones of Bolivia where altitude, climate, and cultures differ. Dr Rubin de Celis has assembled a multidisciplinary team of investigators and is studying the knowledge and practices of apple farmers in Peru who are affected by the modernization of cultivation methods such as multiple crops and chemical inputs. Dr Sansur has studied the agricultural practices of Arab farmers on the West Bank, who have to contend with such problems as pesticide labels written in Hebrew.

Drs Kimani and Mwanthi have carried out an interesting study in Kenyan rural communities, specifically assessing people's knowledge, attitudes, and practices in spraying, storing, and disposing of pesticides. They have used the information to design an education program that may reduce the hazards of pesticide use by farmers and other members of rural communities.

Practices in packaging, labeling, and using pesticides safely were also discussed. Dr Boonlue discusses education and training with respect to communication. Dr Dollimore's paper on safer labeling and packaging raises issues that are pertinent to some of the problems that are continually reported in studies of pesticide poisoning — mainly users' lack of understanding of the precautions necessary for the safe use of any chemical input in agriculture.

Laws, regulations, and access to pesticides

The distribution of pesticides to end-users is not often addressed by health professionals. Researchers frequently carry out surveys based on official records of importation and sales collated by the government and its affiliated agencies. However, as is shown by Professor Mbiapo, official data often do not reflect the real situation. Rather, access to pesticides follows the vagaries of the black market, smuggled goods, and alternative marketing. Good regulatory control must be based on solid data. In his paper, Professor Maroni discusses the use of human data as a basis for pertinent regulation of pesticide use.

Several industrialized countries have recently undertaken to review their pesticide-registration procedures. Such experiences could form the basis of either similar reviews or the actual establishment of up-to-date regulations in developing countries. Dr Versteeg's paper expands on Canadian experience in this area. However, even in countries where the regulation is nonexistent or its enforcement too weak to make a difference, it is necessary to protect users. The FAO has published a voluntary code of conduct for pesticide manufacturers (FAO 1986). Dr Loevinsohn discusses a solution to making that code effective in countries where the implementation of regulations is difficult.

Information will remain the major weapon in the prevention and treatment of pesticide poisoning. Professor Mercier, manager of WHO's International Programme of Chemical Safety provides up-to-date information on this aspect of health promotion in relation to pesticide use.

How are we to promote prevention in developing countries? Many avenues have been looked at and others are being explored. Dr Sekimpi discusses the role of occupational-health services in the promotion of safe pesticide use and the infrastructural requirements of this option. Professor Xue and colleagues describe their experience near Shanghai where a primary health-care service is engaged in a program to reduce the intoxication of local farmers by pesticides.

Modern alternatives for pest management

New substances

As pests develop resistance to existing pesticides, the search continues for new compounds and methods to combat them. Dr Tordoir presents some interesting material on the development of safe pesticides. His paper concisely describes the process that should be followed to ascertain the safety and efficacy of new substances.

One new avenue of research is in the area of botanical substances that have pesticidal activity. Many such compounds have been identified and are being investigated further. For example, pyrethrin, which is extracted from chrysanthemums, is used in the preparation of natural insecticidal formulations (Gombe and Ogada 1988). However, a number of synthetic analogues, pyrethroids, are also being manufactured and are proving effective.

Some plant-derived substances do not appear to need sophisticated processing. A number of natural molluscicides that show promise in the control of snail-transmitted schistosomiasis have been identified in Africa and the Middle East (El Sawy et al. 1987; Lemma 1965). Dr Legesse presents information on one such molluscicide, endod. Dr Legesse was awarded the 1989 Swedish Right Livelihood Award for his work on this natural compound and is involved in a major project to conduct toxicity trials on endod. Some results obtained in a study of another natural molluscicide, damsissa, are presented by Dr Duncan, who has been involved as a consultant with the testing of this product.

Other products are not ready for use, but offer some promise for both agricultural and public health applications. Professors Philogène and Lambert describe the process involved in the development of such botanical compounds.

Biological pest control

Pest species have pathogens to contend with and it is possible to make use of some of them both for agricultural and public health purposes. For example, *Bacillus thuringiensis* and *B. sphaericus* are being used to control mosquito larvae in the fight against such arthropod-borne diseases as malaria, dengue, yellow-fever, filariasis, and encephalitis (Amonkar et al. 1988). New information on the use of this bacterium in Canada and Egypt is presented by Dr Morris in his paper on biological alternatives to chemical pesticides.

Bacillus thuringiensis has been considered innocuous to nontarget species. However, the microbe has been isolated in clinical cases where an effect could not be ruled out (Green et al. 1990). Although this microbial pesticide may not affect healthy individuals, patients who are already immunocompromised may be more susceptible to infection. Given the proportions of the acquired immune deficiency syndrome (AIDS) epidemic in some areas of Africa, the repercussions of using *B. thuringiensis* should be investigated carefully.

Another effective way to combat pests in both agriculture and public health is to promote their destruction by natural parasites and predators such as *Trichogramma chilonis* and a number of larvivore fish. Mr Hagerman discusses the use of this parasite and another, *Euborellia annulata*, in the protection of eggplants and describes a comparison of biological control and chemical control methods in the Philippines.

Integrated vector and pest management

Although pesticides are now a part of our lives, their use can be made safer by careful planning. One method is integrating them with sound ecological practices. Although this has already been explored for many years by agronomists and farmers, the public-health specialists have only recently joined the fray. Dr McKay provides an overview of integrated pest management as practiced in agriculture, specifically discussing examples of work being carried out in the Philippines and in China. Dr Wijeyaratne broaches the subject in relation to environmental management aimed at controlling vector-borne diseases. He elaborates on the history of vector control, discusses past successes and failures, and focuses on some promising strategies now being tested.

Old methods can be modernized through the use of pesticides. For example, bed netting and curtains are being impregnated with pyrethroids in Africa to prevent malaria transmission (Rozendaal 1989). In China, a number of trials of impregnated bednets have been successful.

Safe equipment, education, and training

For the Third World farmer, safe, affordable spraying and protective equipment are not always available. Equipment is often difficult to keep in good repair because parts for imported products are not easy to obtain in developing countries (Jusoh et al. 1987). Developing a national capacity to produce good quality equipment with easy access to parts would go a long way toward reducing occupational risk in these countries. Dr Jusoh et al. discuss such a program undertaken by the Malaysian Agricultural Research and Development Institute.

There is also a dire need for research on protective clothing that is appropriate for hot, humid tropical conditions. Many investigators have shown that pesticide poisoning can often be traced to the absence of body protection during spraying. Drs Chester and Sabapathy present data from studies of protective clothing developed and tested in tropical settings.

Drs Chase and Supapong have been involved in a project aimed to increase the awareness of medical students in Thailand of the problem of pesticide poisoning. The objectives of this project are to sensitize physicians and prompt them to think critically about the public-health aspects of this problem. Details of the project and the lessons to be gained from it are described in their paper.

Conclusions

The subject of this volume is the impact of pesticide use on health in developing countries. Many related and relevant topics are discussed. The symposium organizers hope that the many discussions carried out during the meeting will act to promote programs that ensure safer pesticide use. Issues relating to alternative strategies for vector and pest management will also encourage research into such practices, not as replacements to chemical management, but rather as adjuncts to it.

The research presented at the symposium in many cases points to the gaps in our knowledge, which may will lead to pertinent studies to allow safer pest and vector control. Dr White's paper provides an excellent perspective of current epidemiological approaches, discussing the potential of research as a basis for community action. Suggestions for further research addressing some missing knowledge are invaluable to those of us concerned with this problem.

Dr Durham was given the difficult task of preparing an overview. In his review of all the papers, he summarizes the findings and needs in this field.

The key to the future appears to lie not in discarding pesticides, but in integrating them into sound practices for pest and vector management. Many such alternatives are either described or suggested. Many different disciplines are represented, and scientists from both industrialized and developing countries join forces to find safe and efficacious solutions to the management of agricultural pests and disease vectors in developing countries.

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