ENVIRONMENTAL POLLUTION BY PESTICIDES

Edited by **C. A. EDWARDS**

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Preface

The persistent organic pesticides have saved millions of lives by controlling human disease vectors and by greatly increasing the yields of agricultural crops. However, in recent years man has become ever more conscious of the way in which his environment is becoming increasingly polluted by chemicals that may harm plants, animals or even himself. Amongst these chemicals the organochlorine insecticides have been well to the fore as a major cause of anxiety to ecologists, not only because they persist so long, but also because of the readiness with which they are taken up into the bodies of living organisms, especially the fatty tissues of both animals and humans.

The extent and seriousness of the potential hazards due to these chemicals still remains to be fully defined. Our information on the occurrence of residues in the various parts of the environment is very uneven and localized. For instance, whereas we have a great deal of data on residues in North America, we know virtually nothing about the extent of pesticide contamination in Africa, South America and much of Asia, although large amounts of organochlorine insecticides have been used in these areas.

The emotional impact of the possibility of serious contamination of the human environment by extremely persistent chemicals has resulted in vociferous clashes of opinion between those ecologists who take the view that all pesticides are bad and should be banned, and agriculturalists and others who consider that continued use of large quantities is essential to the survival of humanity. It seems most likely that between these two extremes lies the saner approach, of controlling pests by alternative means, minimizing the uses of persistent pesticides and investigating more fully the possible hazards caused by their continued use. Such a balanced and considerate approach to the problem necessitates the availability of as much information as possible in a concise form, because the available literature on the subject is enormous. This book, *Environmental Pollution by Pesticides,* attempts to do this, by bringing together the available data on pesticide residues, not only in plants and animals, but also in air, water and soil, each chapter being written by a recognized authority in his or her field. Wherever possible, information is provided in each chapter on the following aspects: the amounts of residues commonly occurring, the principal sources of the residues, factors influencing the persistence of the residues, hazards caused by the residues, methods of minimizing or removing residues from the environment and possible further investigations.

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If we have succeeded in presenting a balanced picture of possible environmental hazards due to the persistent pesticides, to a wide audience of scientists and interested laymen, we shall have achieved our aim.

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Introduction

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With the slow development of civilisation, so has man gradually realised the extent to which pests harm his crops, annoy him and transmit diseases, both human and those of domestic animals. The use of chemicals to kill pests is not a new concept; about A.D. 70 Pliny the Elder recommended that arsenic could be used to kill insects, and the Chinese used arsenic sulphide as an insecticide as early as the late sixteenth century. The use of arsenical compounds has continued, and, during the early part of the twentieth century, large quantities of such compounds as lead arsenate were used to control insect pests. Another arsenical compound, Paris green (copper aceto-arsenite), was extensively applied to pools and standing water in the tropics, in attempts to control malaria-transmitting mosquitoes.

It was not realised at the time how persistent arsenical pesticides were, although it is now known that they can persist in soil for up to 40 years, and many orchard soils still contain large amounts of these chemicals. For instance, in a recent survey of arsenic residues in arable soils in Canada, residues of arsenic ranging from 1.1 to 121.0 ppm were reported (Miles, 1968). Other inorganic compounds used as insecticides and fungicides contained antimony, boron, copper, fluorine, manganese, mercury, selenium, sulphur, thallium and zinc as their active ingredients. Although these compounds were not very effective as insecticides, many were so persistent in soil that there were instances of crops being damaged by their residues in soil.

The era of synthetic organic pesticides began about 1940. These chemicals were so successful in controlling pests that there was extremely rapid and general adoption of them and development of new ones. This has progressed so rapidly, that today about 1,000 pesticide chemicals are in common use around the world, of which about 250 are commonly used in agriculture, including about 100 insecticides and acaricides, 50 herbicides, 50 fungicides, 20 nematicides and 30 other chemicals. Only a few of these chemicals persist for more than a few weeks or at most months, in soils or water, and of those that do, most are the organochlorine insecticides, which include aldrin, dieldrin, chlordane, dicofol, endosulfan, endrin, lindane, DDT, heptachlor and toxaphene. All these insecticides are toxic to insects and other arthropods at very low doses, and are so persistent that few annual treatments are necessary to maintain pests at low levels; thus costs are low. As more of these chemicals were developed and the use of others extended, it seemed likely that many of the more serious agricultural and medical pest control problems would be solved, particularly because the mammalian toxicity of most of these insecticides was low, and there were few hazards to the pesticide operators.

It is now well established that the benefits the organochlorine insecticides conferred on mankind during the early years of their use were great. Knipling (1953) estimated that during the first decade of use, DDT saved five million lives and prevented 100 million serious illnesses due to malaria, typhus, dysentery and more than 20 other insect-borne diseases. In agriculture, it has been calculated that, even after the effective use of these pesticides, pests still cause annual losses of about $4,000,000,000 in the United States, and as much as $21,000,000,000 on a world scale, so these losses, if persistent chemicals were not being used, would be astronomical.

Although it was known that organochlorines were very persistent, up till the early 1950's there was little anxiety as to possible long-term ecological hazards caused by their use. There was some evidence that large residues in soil could be phytotoxic, small quantities of some were reported from plant and animal tissues and in cows' milk, and there were some instances of fish being killed when water was sprayed in anti-malarial and other pest campaigns, but all of these side-effects were accepted as slight, but unavoidable hazards, and of little concern.

However, during the 1950's and the early 1960's reports of large residues of these insecticides in soils, and small amounts in water and at the bottom of streams began to appear in the literature. Dead birds were sometimes found close to sprayed fields and woodlands, or fields planted with insecticide-treated seed, and numbers of dead fish were sometimes seen on the surface of water after spraying operations. There were ever-increasing reports that organochlorine insecticides were stored, not only in invertebrate and vertebrate tissues. but were also concentrated into the upper trophic levels of food chains. These discoveries began to cause concern about possible long-term ecological effects of the large quantities of insecticides being used, sometimes quite indiscriminately.

Eventually, came the realisation that there were appreciable quantities of pesticide residues in the biota and physical environment of the polar regions; that there were large residues in certain birds, mammals and human beings; and that measurable quantities were present in the atmosphere; and these findings produced a wave of reaction against the persistent pesticides, resulting in quite stringent restrictions or bans on their use in many countries in Europe and North America. In spite of this, the overall amounts of pesticide chemicals manufactured have continued to rise steadily.

In the United States, the annual production of pesticides has risen from about 300 million pounds in 1954 to over 1,200 million pounds in 1973. Of these amounts, about 30 million pounds were organochlorine insecticides, and since other countries also manufacture these chemicals, there is a continual addition to the environment of such large amounts of these extremely persistent compounds that it is giving rise to considerable anxiety among many ecologists.

Certainly, there is now little doubt that the organochlorines, especially DDT and to a lesser extent dieldrin, are major long-term contaminants of the total environment. Thus, global pesticide contamination is so very extensive that Gunther (1966) claimed that 'a qualified pesticide residue analyser with proper equipment could find measurable DDT in any nonfossil sample presented to him, and with enough time and patience could find several other pesticides as well'.

This demonstrates that, currently, scientists are much more competent to confirm the presence of pesticides in the environment than to assess the significance of such residues. Nevertheless, we still have not completed the essential task of establishing the seriousness of the problem. In view of this, there is little doubt about the need for extensive monitoring programmes for pesticide residues in the environment; these already exist to monitor radioisotopes, and there is no reason that they should not be extended to pesticides and their possible transport between different areas of the world.

The Fish and Wildlife Service, the U.S. Department of Health, Education and Welfare, and the U.S. Department of Agriculture in the United States, and the Nature Conservancy and the Ministry of Agriculture, Fisheries and Food in Great Britain, and equivalent organisations in many other countries, are now regularly monitoring residues of persistent pesticides in soil, water air and in the flora and fauna. Many other scientists are also working on these problems, either independently or in association with government organisations.

Nevertheless, the monitoring of residues in various parts of the physical environment is still inadequate, particularly in Great Britain. The major rivers in the United States are now being monitored annually for pesticide residues at a large number of sampling stations, but in Great Britain, only one or two small-scale surveys have been made. The monitoring of soils for pesticides is much more sporadic, both in the U.S. and in Great Britain, and so far has been mainly confined to agricultural soils, so that there is little information on the amounts of pesticides that occur in the large areas of untreated land. When we have more information on the amounts of pesticide residues in untreated areas, we can assess the possibilities of global transport much better, and such data is essential for adequately assessing potential hazards due to pesticides. Moreover, we have little data on pesticide residues in the under-developed countries, although large quantities of persistent pesticides are regularly used in these areas.

We now have some information on amounts of pesticide residues in the biota, but we have much more data on residues in fish, birds and birds' eggs than those in other vertebrates and invertebrates. Pesticide residues have been found in the air and rainwater, but there is still no regular monitoring programme for these media. Enough data on residues in the human diet and in the bodies of human beings in many parts of the world have been collected to assess their possible hazards to man.

Even when we have established adequate monitoring programmes, there still remains the problem of assessing the significance of the residues. Is it most important to preserve the flora and fauna as far as possible in its present state, or are hazards to human health more important?

Much nonsense has been talked about avoiding changes in balance of nature; even if such an essentially static and idealistic concept were ever a reality, most of man's activities combine to disrupt this relationship. Pesticides have often been blamed for catastrophic declines in numbers of wildlife, but probably changes in land and water development and usage exert a much greater influence than do pesticides. It is clearly undesirable to place the existence of certain species of animals and plants at hazard, but it is important to remember that only species that were close to local or general extinction are likely to be eliminated by pesticides.

It is essential to avoid the trap of establishing a simple causal relationship in a particular situation, and then extending it to be an inviolate principle. It is easy to show well-authenticated instances where organochlorine pesticides have caused serious local ecological disturbances, but we have to be cautious in interpreting such instances as a general principle that all organochlorine insecticides are bad, and that all their uses should be outlawed. With a fuller understanding of their environmental impact and potential hazards, they may yet continue to be used for particular purposes and greatly benefit mankind. An unreasoning ban on their use may be just as unwise as a continued thoughtless and widespread over-use.

Since the ecological hazards of persistent pesticides have been fully realised, there has been considerable expansion of research into control of pests by such means as biological control, insect hormones, chemosterilants, attractants and repellents, but, although appreciable success has been attained, it still seems likely that large quantities of pesticides will be needed for some years to come.

Possibly the importance of DDT in the environment has been exaggerated; for instance, it has been suggested that DDT could aversely affect photosynthesis in the oceans, and that this might reduce their productivity or even ultimately the world's oxygen supply. However, it has been shown that it is extremely unlikely and that even if pesticides did appreciably affect photosynthesis, which itself is extremely improbable, there need be little anxiety about oxygen supply.

It seems probable that the greatest hazards of pesticides are to aquatic organisms, which seem to be much more susceptible to them and also to concentrate them into their tissues more readily than do terrestrial organisms. Since the seas are a sink, which ultimately receives a large proportion of industrial chemicals used, perhaps our anxiety should be more directed to possible effects of pesticides on marine organisms. However, it seems likely that life in the sea is endangered much more by other forms of pollutants than by pesticides, which represent only a minute fraction of the total pollutants that reach the oceans of the world.

We certainly need to know much more about global transport of pesticides and we hope that the comprehensive discussion of this phenomenon in Chapters 10 and 12 of this book adequately summarises the present state of knowledge of this phenomenon.

It seems inevitable that the ultimate solution to our environmental pesticide problems must be a compromise which will use the smallest possible quantities of pesticides, combined with other control measures so that environmental pollution by pesticides is kept at a minimum. There seems little likelihood of being able to dispense with the use of pesticides in the foreseeable future but intelligent use of them will greatly reduce the hazards implicit in their continued use.

One of the main difficulties in interpreting environmental residue data is the variability in analytical techniques and sampling procedures. Frequently, data are given in a form which is very difficult to summarise or compare with those produced by other workers. Furthermore, as analytical methods have improved and become more sensitive, so the possible misinterpretations that can be placed upon the data they provide have multiplied. This is particularly true of gas-liquid chromatographic techniques, that rely on relating the position of a peak traced on a chart to one given by a particular compound which is to be estimated. Many different compounds can produce peaks very close together; when peaks are large, well-defined and clearly separated, they usually provide a valid estimate of the amount and kind of residue present if they can be confirmed by paper chromatography or other analytical techniques. However, this is still not invariably so: for instance, when 34 soil samples dating back to 1909-1911 (long before the advent of organochlorines) were analysed, 32 showed apparent insecticide residues. These were eventually attributed to certain interfering soil constituents, but this incident clearly demonstrates the care needed in such analysis (Frazier *et al.*, 1970).

In analyses of extremely small concentrations of residues such as those in air or rainwater, there is much more possibility of error, not only by misinterpreting chromatographic peak traces, but also from contamination of the analytical equipment with small traces of pesticides or related compounds.

For the purpose of this book, it has not been possible to differentiate between analytical data for reliability, and some data may well be suspect; this should be remembered when the data is considered, quoted or discussed. What is more, explanations of contaminations of soil, water or the biota with pesticides may not always be complicated or ecological. For instance, it has been suggested that the minute amounts of chlorinated hydrocarbon insecticides reported from fish and vertebrates in the Antarctic, may be accounted for by insecticides imported into the area with various expeditions; this may well not be so, but such possibilities should be borne in mind when interpreting residue data.

It is important to remember that residues are usually analysed at some particular point in time, and such data can easily be misleading. For example, it is common practice to take only a single set of samples from some compartment of the physical or biological environment, and determine the residues they contain. Such a spot check may have very little value, however, unless reinforced by other data, and may bear little relation to the average amounts that occur in that medium. In the physical environment, such residues can be the remains of a much larger dose, whereas in the biota, they can be the end result of a long process of absorption and concentration. The whole system of movement of pesticides through the environment is essentially a dynamic one, and for a meaningful interpretation, residue data must be seen and studied as such. The most difficult thing to assess from the residue data that is currently available is not the *status quo,* but the changes that will occur if certain actions, for instance banning a particular pesticide, are taken. The information we need is how rapidly residues will disappear from the different compartments of the environment when they are no longer added to, and other methods of pest control are adopted. We also need to known if the residues that exist are of any real importance, or if the organisms living in a contaminated environment can successfully adapt to such chemicals. Our environment is already full of alien chemicals, but we still do not know whether the further addition of these pesticide residues is important.

One of the more important ways in which persistent pesticide residues can be prevented from becoming a major world problem, is by legislation whenever excessive amounts of these chemicals are reported in food, animal tissues, soil or water as a result of monitoring surveys. So far, the more stringent legislative regulations have involved the permitted amounts of pesticides in human foodstuffs. U.S.A., Canada, U.S.S.R., Japan and most European countries have enacted extensive legislation, and many countries have some tolerance limits on the permissible amounts of pesticides in foods. Such tolerance limits often have a built-in safety factor of at least 100 times known toxic levels. Naturally, the enforcement of such legislation is expensive, involving spot analyses of large numbers of samples, for a wide range of pesticides. Fortunately, although there are very large numbers of pesticides in use, only a few chemicals are extensively used and likely to occur in foods, so the analyses can be restricted to those likely to have been used on the crop or animal from which the food was produced. With more international cooperation, hazards due to pollution by persistent pesticides can be kept to a minimum. It is clear that if, as seems likely, the use of persistent pesticides continues, then it is essential that adequate monitoring of residues is maintained. Although there is little evidence that the small amounts of persistent pesticides in the atmosphere or other parts of the environment are harmful, we cannot be sure that there are no harmful side-effects and, wherever possible, less persistent materials should be used.

How then can we assess the future hazards due to persistent pesticides? Even if no more were to be used, it seems probable that there would be some residues present in the environment for several decades to come. However, although their use is decreasing in Europe and North America due to legislation and various restrictions, their total production is still increasing, and it is difficult to foresee how long this will continue. As long as the demand for more food continues no doubt they will still be used. If, as seems probable, at least some degree of global transport of pesticides is a reality, it seems likely that they will remain a potential environmental hazard.

Fortunately there are extensive programmes of research into amounts of residues present and their long-term effects, in many countries, with a resultant increase in our knowledge of the hazards involved. For instance, we still have no evidence of them causing any serious harm to human beings, and there are now indications that human body burdens of persistent pesticides do not continue to increase indefinitely, but, instead, tend to level off even after excessive exposure to these chemicals as by pesticide workers.

There is evidence that the persistent pesticides are sometimes harmful to some species of wildlife and may even threaten the existence of others. However, these effects do not seem to be drastic and it seems unlikely that really serious damage will occur to any species of wild animal, other than those that are already under severe environmental stress for other reasons.

There is an extensive scientific literature on pesticide levels in, and effects of them on, various components of the environment. Many of the more important papers are summarised in the various chapters of our book, but since many of the subjects discussed are still controversial, some discussion of the earlier books and reviews of the subject may be of value.

The first major publication was the book *Silent Spring* (1962), which, by greatly exaggerating the potential hazards of persistent pesticides, focussed much more attention on the problem, and in this way helped to stimulate an awareness of the need for research, and thus indirectly contributed to our knowledge of the status of pesticide residues in the various sections of the environment, although we still know little more of the significance of these residues. This book was followed by a variety of very relevant reviews and symposia concerning the persistence of pesticides in the environment and their ecological effects. These include *Pesticides and the Living Landscape*, a much more balanced review of the influences of pesticides than *Silent Spring*. In 1964 a comprehensive annotated bibliography entitled *Pesticides in Soils and Water* was published by the U.S. Department of Health, Education and Welfare; in the following year another excellent review, *Residues of Chlorinated Hydrocarbon Insecticides in Biological Material* (Marth, 1965), concerned residues in plant material, and in 1965, Moore reviewed the effects of pesticides on birds in Great Britain. Also in 1965, there was a symposium entitled *Research in Pesticides* (Chichester, 1965) which contained several interesting papers on the persistence of pesticides in the environment. In 1966 there were three symposia, *Pesticides and their Effects on Soils and Water* (Anon, 1966), *Agriculture and the Quality of Our Environment* (Brady, 1966), and a third, *Organic Pesticides in the Environment* (Gould, 1966), published by the Chemical Society of America. Papers read at an international symposium organised by the British Ecological Society were published with the title *Pesticides in the Environment and their Effects on Wildlife* (Moore, 1966), and a book, *That We May Live* (Whitten, 1966), was as much biassed in favour of pesticides as *Silent Spring* was against them.

A review of persistent soil insecticides also appeared in 1966, particularly emphasising factors influencing their persistence in soil (Edwards, 1966). The following year, Moore (1967) published *A Synopsis of the Pesticide Problem,* which dealt with ecological aspects of pesticide usage, and a review by Newsom reviewed the consequences of insecticide usage on non-target organisms, but this review, although good, was limited in scope and coverage. A popular book by Mellanby (1967), *Pesticides and Pollution,* discussed the more general aspects of pesticide pollution. In 1968, Stickel produced a review, *Organochlorine Pesticides in the Environment*, which briefly discussed the ecological hazards to wild animals of pesticides. A good review on *Pesticides and Fishes* (Johnson, 1968) had an excellent bibliography. The proceedings of a symposium with the title *Chemical Fallout–Current Research on Persistent Pesticides* (Miller and Berg, 1969) contained some excellent papers, especially one, 'Organochlorine insecticides and bird populations in Britain'; and in another, Robinson (1969) summarised the uptake of organochlorine insecticides into human beings under the title 'The burden of chlorinated hydrocarbon pesticides in man', which particularly emphasised the deficiencies in sampling and analytical techniques and produced a mathematical model to account for the metabolism of pesticides in the human body.

Frost (1969) reviewed global aspects of pesticide contamination, and in 1970 the proceedings of a symposium *Pesticides in the Soil* was also published. Edwards (1970) produced a book *Persistent Pesticides in the Environment,* which attempted to assess and evaluate the amounts of pesticides in all compartments of the environment. The same author (1970, 1973) reviewed the effects of pesticides residues on the whole soil ecosystem. A book *Pesticides and Freshwater Fauna* (Muirhead-Thompson, 1971) and the first of a five-part series edited by Robert White-Stevens, entitled *Pesticides in the Environment*, appeared in 1971.

There have been several recent governmental reports, including the 'Report of the U.S.D.A. Committee on Persistent Pesticides' (1969), and the 'Report of the Secretary's Commission on Pesticides and their Relationship to Environmental Health' (Mrak Report, 1969) from the U.S.D.H.E.W., a 'Further Review of Certain Persistent Organochlorine Pesticides used in Great Britain' (1969), and the 'Third Report of the Agricultural Research Committee on Toxic Chemicals' (1970), also from Great Britain.

One of the main aims of our book is to present factual information on the seriousness and extent of ecological hazards due to pesticides, carefully assessed by leading authorities in the various fields of pesticide pollution. With such information, the scientist and layman may be able to make a much more balanced judgement than he could from some of the articles and books that appear in the popular press and are often emotive and written with an appeal to the sensational. Already, too many far-reaching decisions have had to be made based on inadequate information.

The compilation of data and treatment of the subject in this book is made much more comprehensive by having the chapters written by different authors, each of whom is a recognised authority in his or her field. Moreover, one of the benefits of a book written by a range of different chapter authors, is the variety of viewpoints and emphasis that is given, and it is hoped that in this way the reader will obtain a much broader and more balanced picture than he could from a book written by a single author, however unbiassed he might be. To retain an international flavour to the data, chapter authors have been recruited almost equally from Europe and North America, so there should be no undue emphasis, other than that inevitable where more data are available from North America than from other areas of the world.

We hope that the data presented will not only illustrate the current state of our knowledge of persistent pesticides in the environment, but will pinpoint those areas where more information and research is needed. If it serves to provide those bodies concerned with legislation and environment pollution, with a factual basis for their deliberations and to present a balanced picture for the interested scientist and layman, its main purpose will have been fulfilled.

For references: see Appendix (General references) page 515.