Control of Pesticide Applications and Residues in Food

A Guide and Directory – 1986

Edited by Bengt v Hofsten and George Ekström

SWEDISH SCIENCE PRESS

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Swedish Science Press
P.O. Box 118
S-751 04 UPPSALA
Sweden

Cover: Titti Apler, ORD & FORM AB
Production: ORD & FORM AB, Uppsala, Sweden, 1986

ISBN 91-86992-01-5

Preface

The purpose of this book is to encourage international cooperation in the control of pesticides and similar compounds used for protecting food crops in the field and after harvest. Insects, rodents, nematodes, fungi and bacteria destroy huge quantities of food and feeds, and modern agriculture is using increasing amounts of pesticides, fumigants and preservatives to prevent such losses. Agrochemicals are also widely used for weed control and to regulate the growth of food crops.

The manufacture of many agrochemicals frequently involves procedures which are potentially dangerous. Recent accidents have highlighted this, but problems of this kind are outside the scope of this book.

The handling and application of some pesticides also involves great personal hazard. Strict rules for their application in the fields or storage houses are therefore essential. Discharge of agrochemicals into the environment – whether by negligence or accidentally – may also have serious consequences to the environment and public health. Tighter controls should be introduced both in developing and industrialized countries. An international Code of Conduct on the Distribution and Use of Pesticides has been adopted by the 23rd Session of the FAO Conference to curb pesticide abuse. The Code has been attached to this book as Appendix 5.

The increasing international food trade makes it necessary to harmonize national regulations on pesticide residues and other food contaminants. We hope that this book will pave the way for international collaboration in this field. Many consumers are worried, and it is necessary to improve collaboration between scientists, national control authorities and consumer organizations.

In 1983, the Swedish National Food Administration published a draft edition of this book. This new edition is updated with new information from international organizations and individual countries. It is also enlarged through inclusion of six introductory chapters giving background information, and we hope that this will provide an impulse to countries which have not yet developed an effective control organization.

We gratefully acknowledge the valuable collaboration of contributory authors and by authorities and organizations submitting information. It is difficult to avoid typographical errors and incomplete information in a book of this kind. The majority of contributors have commented on the proofs, but the responsibility for any omissions or errors is ours alone.

To widen the readership, we have provided a translation of the headings in chapter 8 into Spanish, French and Russian on the coloured insert.

A grant from the Swedish Products Control Board to cover part of the production cost is gratefully acknowledged.

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Readers are kindly requested to communicate additional information, corrections and suggestions for improvements to the Editors under the following address:

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The Swedish National Food Administration

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Agrochemicals as environmental pollutants

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1. Introduction

Increasing amounts of agrochemicals, including fertilizers, pesticides and growth regulators, are being used in developed countries, and progressively larger amounts are being exported from Europe and U.S.A. to the developing countries where domestic production is also increasing rapidly. The environmental and human health hazards due to the increased use of such chemicals has been controlled effectively by legislation and restrictions in developed countries, but the present period could be critical in developing countries if the use of chemicals in agriculture and disease prevention is allowed to develop haphazardly.

(a) Usage of agrochemicals

Data on the usage of pesticides in any country is extremely difficult to obtain because manufacturers are usually reluctant to disclose such information and, in developing countries, records are often incomplete and there is little government control of the use of such chemicals.

A survey was made by FAO in late 1974 included predictions on future use of pesticides up to 1977 (FAO, 1975). This survey was based on a detailed questionnaire sent to 99 governments asking for details: (i) of herbicide, insecticide and fungicide consumption 1971 to 1973; (ii) estimates of future consumption from 1975 to 1977; (iii) predicted pesticide imports for 1975 to 1977.

Only 50 countries returned completed questionnaires and, of these, only 38 provided full data as requested. Of these countries, Argentina, Chile, India, Mexico and the Sudan used more than 10,000 tons of active ingredient of pesticide per year and of these India was by far the largest user (25% of the total consumption). Eight other countries, Cyprus, Guatemala, Indonesia, Korea, Lebanon, the Philippines, Sri Lanka and Turkey used more than 2,000 tons of active ingredient of pesticide annually. Other large users were Brazil, Egypt and Pakistan but they did not provide data. There was some evidence that the larger users were those who returned the questionnaires.

The total pesticide consumption of the 38 countries in 1973 was 160,000 metric tonnes of which 5,000 tonnes were herbicides, 106,000 tonnes insecticides and 49,000 tonnes fungicides. Overall, about half these pesticides were produced domestically but this varied greatly between countries.

There are some reports in the literature from which some assessment and predictions can be made of the usage of different agrochemicals internationally. Most published data are based on the financial value of such chemicals rather than on the tonnages produced. Data are particularly hard to obtain on the extent of the use of fertilizers, although there is some information from South-East Asia. Fortunately, hazards due to fertilizers seem slight and concern mainly the pollution of waters with nitrates, potassium and phosphates with the possibility of causing eutrophication. However, potassium has limited mobility in soils and phosphorus is virtually immobile. Nitrates are quite readily leached and these could pose a hazard. Most of the evidence is that although levels of nitrate nitrogen rise where inorganic fertilizers are used regularly, they are not serious. This paper will not concern itself with problems relating to fertilizers, since there are few reports of their effects on human health, and there seems little evidence of serious hazards.

Overall pesticide usage in agriculture, in terms of amounts applied per ha., has been very much greater in Japan, Europe and the United States than in the rest of the world (Tables 1 & 2) (Figure 1) although China is also a major user. However, this pattern is changing, the fastest growing market being Africa, with sales increases of 182% between 1980 and 1984. Other rapidly expanding markets are Central and South America (32%), Asia and the Far East (28%) and the Middle East (26%) (Tables 3 & 4). Clearly, the predicted use of pesticides in 1984, showed some uses in developing countries approaching those in developed countries. Although herbicide sales have been greater than those of insecticides and fungicides in developed countries and are increasing rapidly, this pattern is not being repeated in developing countries, where by far the greatest proportion of pesticides used are still insecticides (Table 5) (Edwards, 1977). Most evidence is that the relative proportions of insecticides and herbicides used in developing countries are unlikely to change greatly in the future. Currently, about 90% of the pesticides used are on agricultural

Table 1. Areas and Nations in Order of Pesticide Usage per Hectare and in Order of Yields of Major Crops.

Area or Nation	*Pesticide Use g/ha*	*Rank*	*Crop Yields Kg/ha*	*Rank*
Japan	10,790	1	5,480	1
Europe	1,870	2	3,430	2
United States	1,490	3	2,600	3
Latin America	220	4	1,970	4
Oceania	198	5	1,570	5
Africa	127	6	1,210	6

Table 2. Regional Summary of Use of Agricultural Pesticides in Selected Asian Countries and Austrialia, 1981. (Quantity of active ingredient in metric tons; value[a] in thousand US Dollars).

Country	*Insecticides*		*Fungicides*		*Herbicides*		*Total*	
	(Active ingredient)	*Value*	(Active ingredient)	*Value*	(Active ingredient)	*Value*	(Active ingredient)	*Value*
Australia	2 306	45 669	1 441	10 653	6 031	107 134	9 778	163 456
China	111 950	n.a.	11 050	n.a.	10 075	n.a.	133 075	n.a.
India	23 954	n.a.	2 571	n.a.	723	n.a.	27 248	n.a.
Indonesia	4 845	43 801	906	2 871	833	11 221	6 584	57 894
Japan	35 245	546 593	30 956	107 693	15 257	456 375	81 458	1 536 586[b]
Pakistan	948	n.a.	117	n.a.	36	n.a.	1 101	20 418
Philippines	1 615	14 990	832	5 807	1 062	5 295	3 509	26 093
Republic of Korea[c]	6 358	80 705	5 502	77 292	3 374	39 176	15 234	197 173
Thailand	3 749	36 308	1 780	6 830	64 283	64 283	9 786	107 420

Source: Personal communication

[a] Value not further specified

[b] Including $ US 425 925 of combination insecticide/fungicide

[c] Republic of Korea, 1980

crops, particularly cotton and rice. The remaining 10% is used in vector control of human diseases (Table 6).

There is only limited production of active ingredients of pesticides in the developing countries, most notably in Latin America and India. In most other regions, the active ingredients are imported and formulated locally to the finished product, including packaging and labelling. It is quite likely that there will be a considerable expansion in local manufacturing of active ingredients in the future.

(b) **Reasons for use of pesticides**

(i) *Agricultural crop pest control*

The losses to crops caused by pests are enormous. Good evidence for this can be seen in Table 7 which shows an extremely good correlation between the amounts of pesticides used and yields of crops, with increases in productivity of several hundred per cent after the use of pesticides being not at all uncommon. Crop losses due to pests and diseases of the order of 40% are common, and losses of as much as 75% have been reported. One of the major pests responsible is the locust which has necessitated aerial spraying of hoppers on a large scale, traditionally with dieldrin,

Table 3. U.S. and World Pesticide Markets, 1971–1984[a] User's Level.

Year	*United States Market* *$ billion*	*% change*	*World Market* *$ billion*	*% change*
1971	1.4	–	3.6	–
1974	2.1	49	6.3	77
1980	2.7[b]	28	8.1[b]	27
1984	3.3[b]	19	10.0[b]	24

[a] 1977 price level
[b] Estimated by *Farm Chemicals*

Source: 1971 and 1974: "World Pesticide Markets", *Farm Chemicals,* September 1975, p. 45; adjusted to 1977 price level by EPA.

1980 and 1984: "A Look at World Pesticide Markets", *Farm Chemicals,* September 1977, p. 38.

Today the world market of pesticides is growing faster than in the U.S. and other developed countries. *Farm Chemicals* predicted U.S. pesticide sales of 3.3 billion dollars in 1984, an increase of 19% during the five-year period (*Farm Chemicals,* Sept. 1977). During the same time period, a 24% increase in world sales, from 8.1 billion dollars in 1980 to 10.0 billion dollars in 1984 was predicted. These rates of growth reflect the maturing of the pesticides market, especially in the U.S. and other developed countries where most acreage and livestock, which would benefit from pesticide application, have already come under treatment. They also reflect the fact that the base upon which the rate of growth is calculated has become considerably larger. For example, the projected two billion dollar increase from 1980 to 1984 in the world pesticide market represented a more than 55% increase over the 1971 base of 3.6 billion dollars.

Adapted from UNIDO EX87 (1979)

Table 4. Predicted World Pesticide Market Growth, 1974–1984 User's Level.

Area	*$ Million* *1974*	*1980*	*1984*	*Projected Increase from 1980–1984 (%)*
Western Europe + British Isles	1 301	1 728	1 946	13
Eastern Europe including USSR	527	815	912	13
Midle East (Egypt, Syria, Greece, Turkey, Israël, Lebanon, Sudan)	150	305	386	26
Africa	92	210	593	182
Asia (Iran, Pakistan, Afghanistan, India)	157	244	313	28
Far East including People's Republic of China	480	969	1 245	28
Australasia	96	145	174	20
Central + South America	410	825	1 092	32
North America	1 977	2 812	3 291	17
Total	5 138	8 053	9 961	24

Source: "A Look at World Pesticide Markets", *Farm Chemicals,* September 1977, p. 42.

Table 5. World Pesticide Market (Million $) 1978.

Pesticide	*U.S.*	*Western Europe*	*Japan & Far East*	*Rest of World*	*Total*
Herbicides	1 731.9	705.9	418.8	859.7	3 716.3
Fungicides	189.5	510.9	380.1	458.2	1 538.7
Insecticides	809.4	397.6	718.0	1 103.5	3 028.5

From: Farm Chemicals

Table 6. Estimates of total usage and forecast requirements of insecticides by 103 developing countries for national vector control programmes provided in response to a 1980 questionnaire (expressed in metric tonnes of active ingredient).

Insecticide	*Quantity used*			*Estimated quantity required*			
	1978	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*
azinphos-ethyl	3.2	23.9	31.0	40.3	41.5	41.5	41.5
bendiocarb	–	–	0.007	0.01	0.02	0.02	0.02
bromophos	2.5	0.5	–	4.0	3.6	3.2	2.4
bromophos-ethyl	–	0.13	0.006	0.006	0.006	0.006	0.006
carbaryl	63.9	14.7	8.5	–	–	–	–
chlorphoxim	7.7	13.6	72.8	–	–	–	–
chlorpyrifos	7.8	9.2	8.4	9.9	170.1	186.2	204.0
DDT	18,669.8	25,519.7	28,819.7	28,876.7	29,078.9	36,066.0	30,215.5
dieldrin	43.1	7.7	1.1	1.1	25.5	28.1	31.2
diazinon	0.3	7.0	6.0	6.0	6.0	0.2	0.2
dichlorvos	35.0	42.7	56.0	61.3	65.0	72.5	243.4
dimethoate	9.0	9.3	2.0	17.4	17.6	18.2	18.6
dioxacarb	0.4	0.1	–	–	–	–	–
fenitrothion	241.6	87.4	317.8	327.8	546.5	586.1	680.8
fenthion	45.8	81.5	72.8	89.3	130.2	116.7	119.9
HCH	9,993.7	2,320.7	3,657.7	18,332.7	8,330.6	18,432.5	18.436.8
iodofenphos	0.4	1.2	2.4	2.4	3.0	3.0	3.0
larvicidal oil	8,904.2	3,088.0	7,577.0	7,492.0	7,347.0	7,342.0	7.342.0
malathion	6,629.2	6,951.6	8,134.7	8,539.9	8,472.8	8,327.6	7,896.4
methoxychlor	–	–	0.5	0.7	1.0	1.0	1.0
naled	3.2	41.4	5.0	2.8	4.0	4.0	4.0
phenthoate	–	2.0	2.0	3.0	3.0	3.0	3.0
pirimiphos-methyl	2.2	5.1	14.6	12.6	12.6	12.6	12.6
propoxur	349.3	402.5	459.0	436.9	461.7	66.7	70.6
pyrethroids	1.7	1.1	4.2	7.1	7.9	8.7	8.6
pyrethrum	37.1	46.5	91.4	91.0	91.0	91.0	91.0
temephos	181.1	223.5	247.7	273.2	298.8	601.2	306.2
trichlorfon	2.6	8.0	15.6	10.0	11.6	14.0	15.6
Total	43,234.6	38,909.1	49,607.9	64,638.1	65,129.4	66,026.0	65,721.3

now with other less persistent chemicals. The crop with most pest problems and greatest use of insecticides is cotton. An extremely wide range of pesticides has been used in the tropics; organochlorine insecticides are still used but are being replaced gradually by organophosphorus and carbamate insecticides. Although these may be safer ecologically and do not accumulate in food chains, most of them have a higher mammalian toxicity and present a greater hazard to applicators than the early persistent chemicals, and this is important in developing countries.

Table 7. Estimated losses of potential crop yield (percentages).

Crop	*S. America*	*Africa*	*Asia*
Wheat	31	42	30
Rice	28	36	57
Maize	44	75	42
Sugarcane	44	67	71
Potatoes	44	62	49
Vegetables & pulses	30	39	36
Coffee	47	56	43
Cocoa	48	52	38
Soya beans	32	42	40
Copra	34	30	50
Cotton	42	45	36

Even greater and more significant losses are caused to post-harvest crops, particularly in the tropics, by a multitude of stored product pests, and these are extremely difficult to control. Many insect pests tunnel into grains or beans where it is virtually impossible to kill them with contact insecticides, fumigation being the only possibility. In addition, rodents cause a significant loss of stored products. Even where control is successful, there may be an unacceptable cost in terms of human health because if pesticides are used on stored crops, they can contaminate food supplies seriously.

(ii) *Control of human disease vectors*

Many of the most important human diseases in the tropics are transmitted by vectors or intermediate hosts such as insects, arachnids or molluscs that are best controlled by the use of insecticides, molluscicides or nematicides.

Malaria. There are about 1,900 million people at risk in 102 countries. In 1981, about 10 million cases were reported, mainly from Africa, South East Asia and the Western Pacific. DDT is used for indoor residual application on a wide scale, but resistance to this and other organochlorine insecticides has been reported in 51 species of mosquitoes; the replacement insecticides such as malathion may not be as effective, and are considerably more expensive.

Onchocerciasis (river blindness). This disease is caused by a nematode *(O. volvulus)* transmitted by blackflies of the genus *Simulium.* Control of this disease depends on vector control achieved by applying larvicides to rivers in affected zones. The main chemical used is temephos and the use of *Bacillus thuringiensis* (H14) has been quite effective.

Schistosomiasis. This is caused by a trematode *(Schistosoma)* and is transmitted by aquatic snails; it is controlled by molluscicides applied to aquatic systems; these include niclosamide. It is likely that as new molluscicides are developed, this form of application will increase.

Trypanosomiasis. This disease is caused by a protozoan transmitted by the tsetse fly *(Glossina).* The main method of control are ground spraying the bush habitats of the flies with residual insecticides such as DDT, dieldrin or aerial ULV applications of endosulfan. Specially designed traps, treated with insecticide, have been found to be very efficient and their use is expanding.

Other vector-borne diseases. These include dengue fever, dengue haemorrhagic fever and Japanese encephalitis, all spread by mosquitoes, Chaga's disease transmitted by reduviid bugs, leishmaniasis transmitted by sandflies and lice-borne typhus. Control of these diseases necessitates the use of a number of different insecticides.

Certain control measures which depend upon the aerial application of chemicals to the bush, to water and to human habitats can result in considerable exposure and potential risk to wildlife and human health. They can also kill fish on a wide scale or become introduced into food chains, with predatory species at greatest risk.

A WHO study showed that greatest demand for urban vector control was for insecticide formulations for larviciding and space-spraying, the commonest formulations used being emulsion concentrates or ULV concentrates. In uban areas, organochlorines are now little used. The organophosphate insecticides used in larger quantities include chlorpyrifos, dichlorvos, fenitrothion, fenthion, malathion, pyrethrins, pyrethroids and temephos. Overall pesticide requirements are substantial, the cost being estimated at over 100 million US dollars annually.

(c) **Environmental effects of pesticides**

Because pesticides are applied to small or large areas of crops or water, they can cause the pollution of food, air, water and soil, so that the environmental effects of these chemicals can take many forms. There have been many reviews on this subject (Edwards, 1973a, 1973b) so the discussion here will be limited to relatively brief comments.

(i) *Effects on man*

Many pesticides are broad spectrum biocides, toxic not only to target arthropods but also to vertebrates and man. Unless applied carefully, some of them can kill or affect the applicators adversely or even kill them. Some pesticides, particularly some of the organochlorine insecticides, can accumulate in the tissues of plants and animals and their residues increase in concentration in some animals near the top of the food chain. Considerable care is needed to avoid the pollution of human food with pesticides, and this is achieved in developed countries by regular market basket surveys but in developing countries is still common.

(ii) *Ecological effects*

Much has been written about the general ecological effects of pesticides. They tend to decrease animal species diversity, accumulate in food chains and can have considerable indirect effects on predatory species. Some are extremely toxic to specific groups of anmals such as fish or birds. The effects can be localized and usually transient, particularly in soil, but much more widespread and general effects are possible when air and water become heavily contaminated and the chemicals reach areas far from the site of application. Some pesticides are persistent and can affect ecosystems for a number of years (Pimentel and Edwards, 1982). However, less persistent chemicals that are very toxic broad spectrum biocides can also have quite drastic and long-lasting environmental effects.

Although relatively serious wild-life kills have been reported from many areas of the world, there seems to be little evidence of the eradication of any species from an area, although populations of some species may be depleted locally, sometimes quite drastically.

(iii) *Development of new or more serious pest problems*
Pests tend to live in balance with their natural enemies and their numbers are kept at least partially in check. It has been a common experience that, when pest control by chemicals is introduced to a new crop and/or area, that spectacular increases in yields are often obtained for several seasons. Gradually, these increases become harder to maintain even when new pesticides are used. Usually this is because few pesticides are relatively specific to pests and not only the pest is killed but also its natural enemies become gradually depleted. This increases the need for further chemical control. Additionally, an insect species which may have caused no damage because it is kept completely in check by predators and parasites, can become a serious new pest. The best examples of this are with cotton, where numbers of pest species in some developing countries have increased from 3 to 4 to as many as 10. Finally, frequent use can cause the development of resistance to one or more of the pesticides commonly used. Thus, a dependence on continued pesticides use has been created.

2. Effects of agrochemicals on human health

Many pesticides, being biocides, have a high mammalian toxicity and necessitate considerable precautions in their use. Even in developed countries, there have been many instances of human mortality or side effects due to a wide range of causes, in spite of precautions and protective clothing during application. In hot and humid developing countries, with less training in safe application of pesticides, these problems are accentuated.

(a) **Ways in which man is exposed to pesticides**
(i) *Accidental exposure*
Some of the most serious effects of pesticides are because of the potential for accidental exposure to lethal or harmful doses of these chemicals. It has been estimated that pesticide poisoning accounts for about 5% of all incidents of accidental poisoning by chemicals. Such accidents can be to the applicator of a pesticide and can come from the concentrate or through exposure during spraying or other treatment operations. Proper protective clothing can minimize such exposure, which is mainly through the skin or by inhalation. However, carelessness in using such clothing, particularly in hot weather when it is uncomfortable, and ignorance as to the importance of such protection causes numerous poisonings to occur on a worldwide basis. In developing countries, protective clothing may not be available, and under tropical conditions one may not expect it to be used conscientiously. This is accentuated where pesticides may not be labelled properly or in the local language, and the applicators not adequately educated or trained. No reliable statistics exist on the incidence of pesticide poisoning, particularly in developing countries. Many affected people do not associate their illness with pesticides and deaths often go unreported. In 1972, a WHO Expert Committee on the Safe Use of Pesticides (WHO, 1973) concluded that about half a million cases of accidental poisoning occurred per annum with a mortality rate of about 1% in the more

developed countries and possibly even more in developing countries where records of such incidents are poor. A typical example occurred in 1976 when 2,700 out of 7,500 field workers engaged in malaria control in Pakistan became poisoned by malathion and five of them died.

Other types of accident which may involve larger numbers of people, are those due to unsafe packing and leakage of pesticides in storage or transport. On a number of occasions food has been contaminated in this way. Parathion and endrin have been involved most frequently in such accidents (Hayes, 1975). The commonest cases of accidental poisoning by pesticides are those where grain dressed with pesticides has been eaten accidentally (WHO, 1974). There are many examples of such accidents. For instance, over 6000 people in Iraq were admitted to hospitals with symptoms of food poisoning in 1971–72 and more than 500 died, due to eating bread which had been prepared from cereals treated with methyl mercury fungicide. Other accidents have occurred when insecticides that have been found to be effective against one type of pest have been incorrectly and dangerously used for treatment against others, such as bed bugs or body lice, with consequent poisoning of members of whole households. In the tropics, containers that have contained pesticide concentreates are attractive for household use; if such containers are used for carrying or cooking consumables, poisoning my occur. Aerial spraying or drifts have caused clinical effects in people in nearby areas (Edwards, 1973a; Rocha *et al.*, 1973). It is not uncommon for children to drink pesticides kept in inadequately labelled bottles or containers. One of the most spectacular recent cases was in 1984, where methyl isocyanate gas escaped from a pesticide manufacturing plant in Bhopal, India and more than 2000 people were killed or seriously injured.

(ii) *Occupational exposure*

Workers in pesticide manufacturing and formulating factories may be exposed day after day to pesticides. Although the health of workers is monitored carefully in developed countries, there have still been incidents where human health has been affected. Copplestone (1977) recorded such cases as this in up to 18.4 per 1000 workers in California, USA. Workers in factories or field applicators who spend a large proportion of their time exposed to pesticides, may accumulate hazardous concentrations of these chemicals in their tissues gradually. Between 30 and 40% of all pesticide poisoning has been reported to be of an occupational nature. Nevertheless, there are surprisingly few well-documented cases of chronically affected workers in the pesticide industry.

(iii) *Suicides*

Pesticides present a convenient means of suicide, since relatively small quantitites of such chemicals are usually sufficient to kill a human being, and they are readily available. Symptoms of pesticide poisoning are often unrecognized, so no reliable statistics on the incidence of pesticides in suicide cases exist.

(iv) *Exposure through food*

Pesticides are applied to growing crops and fruits and if the chemical is applied close to harvest, contamination of food is very likely. If animals are treated with pesticides, the pesticides can be taken up into meat, milk and milk products. Fish are commonly grown in water contaminated by pesticides in the tropics. Finally,