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THE TOXICITY OF SOME ORGANIC INSECTICIDES TO FISHES *

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During the past fifteen years a large number of new organic pesticides have been developed and placed on the market. Because many of these are highly toxic to insects and have a residual action, their use has experienced a phenomenal growth. Hundreds of millions of pounds of toxic formulations are used each year for the control of pests and other nuisance organisms. So great has been the success of these materials that control agencies have begun to think in terms of eradication for some vectors and pests. That these new organic

* This paper is a summary of the results of investigations conducted by the Public Health Service on the toxicity of organic insecticides to fishes and other aquatic organisms.

toxicants have been of great value is attested by the control of vector born diseases in many parts of the world, the practically complete eradication of malaria in the United States, and the effective control of many crop pests.

The initial effectiveness of DDT for insect control was so great that the general public came to believe that its use was the answer for all or most vector and pest problems. Control by pesticides has been accepted to such an extent that other control methods have been largely neglected or forgotten. In fly control, for example, many placed complete reliance on chemical control, neglected established sanitation practices, and met difficult problems simply by the application of more insecticide. This has resulted in the rapid development of resistant strains of flies which has necessitated the development of new and more potent insecticides. This tendency to rely on chemical means alone, to seek continually newer and more potent toxicants, and to apply larger and larger dosages for pest control, is responsible in part for the excessive use of toxic materials in certain areas. In addition, pesticides are being used for an ever-increasing variety of control problems. Their use for the control of agricultural pests has had a phenomenal growth. In fact the amounts applied for this and other uses are now so great that they are seriously affecting organisms other than those they are intended to control as for instance, aquatic life. (Ingram and Tarzwell, 1955; George, 1957; Ide, 1957; Graham and Scott, 1958.) It is apparent that some evaluation of the use, and toxicity of these materials to organisms other than those to be controlled must be made if widespread damage is to be avoided.

For effective and efficient control of pests or other organisms there are certain basic procedures or approaches which are applicable in most instances. First, it is desirable to determine the life history and environmental requirements of the organism to be controlled. A knowledge of food habits; requirements for reproduction and growth; habitat requirements; and competitors, predators, parasites, and disease is basic for the formulation of an effective control program. Such information is essential for determining the link in the chain of existence which is most easily broken for the efficient control of the species under consideration.

Such knowledge of environmental requirements is basic to biological control which is, in the long run, the cheapest and the least harmful to other organisms. Further, biological control is generally operative over long periods, and it works continually. Chemical control usually is effective for relatively short periods and is thus a recurring operation. When it is the sole control method used it becomes a very costly operation. In addition, if the toxicant used is not selective the control problem may be made even greater by its continued use as a result of the destruction of competitors, predators, and parasites of the organism it is desired to control. If biological control methods have not been developed or are slow acting or unfeasible, chemical and biological control methods may be combined for a more rapid and effective attack on the pest or vector species. Such a combination of methods has been effectively used by the TVA in malaria control operations.

Second, before a toxicant is widely used for the control of a particular species, its toxicity to other important organisms in the area should be determined. Ideally a pesticide should be selectively toxic for the species to be controlled. Such a toxicant should be effective against the pest species at such low concentrations that it would be relatively nontoxic to other organisms in the environment. If selective pesticides or biological control methods are not available the smallest amount of the selected pesticide which is effective for the control of the problem species should be determined so that application can be kept to a minimum. Tests also should be carried out to ascertain those formulations and methods of application which are least harmful to other species in the biota. When this has been done and if it is found that the toxicant of choice cannot be effectively used without serious harm to other species, consideration should be given to the selection of another material. Often it is desirable to use a pesticide which while not the most efficient for the control of the problem species, is much less toxic to other species of commercial or recreational value.

Extensive field and laboratory studies demonstrated some time ago (Tarzwell, 1947, 1948, 1950; Surber, 1948; Surber and Hoffman, 1949; Hoffman and Surber, 1948, 1949; Lawrence, 1950) that the new organic insecticides were toxic to fishes and certain other aquatic organisms. The increasingly widespread and intensive use of these materials during the past decade has resulted in fish kills in many areas (Rudd and Genelly, 1956). An extensive fish kill due to cotton dusting in north Alabama has been described by Young and Nicholson (1951). It has been shown (Tarzwell and Henderson, 1957) that runoff from an area treated with dieldrin for white fringed beetle control was toxic to fishes in a dilution of one in three.

During the past three years bio-assays have been carried out at the Sanitary Engineering Center to determine the toxicity of the commonly used insecticides to fishes. In these studies the methods suggested by the toxicity subcommittee of the research committee of the Federation of Sewage and Industrial Waste Associations (Doudoroff et al., 1951) have been followed. These studies have shown that, in general, the chlorinated hydrocarbons are more toxic to fishes than are the organic phosphorus compounds. This is due in part to the fact that the organic phosphorus compounds are hydrolyzed to less toxic materials when in water solution.

In the bio-assays with the organic phosphorus compounds, results of which have been reported by Henderson and Pickering (1958), it was found that water quality characteristics such as pH, alkalinity, and hardness within the usual range of natural waters exert very little effect on the toxicity of these compounds to fishes. It appears that at least some of these compounds are more toxic to bluegills than they are to fathead minnows. The toxicities of several organic phosphorus compounds to fathead minnows as indicated by the 96 hour TL_m are listed in Table I and compared to the LD_{50} for houseflies and white rats. Because the mode of exposure is different, the numerical values for the amount of the toxicant which kills half of the test animals indicate only the relative toxicity of the various materials to the different animals. EPN was the most toxic of these materials to fathead minnows, its TL_m being 0.20 p.p.m., but it ranked fourth for flies and about sixth for white rats. These results do not indicate a definite correlation between the toxicity of these materials to fishes and mammals or insects.

TABLE I

COMPARATIVE TOXICITY OF ORGANIC PHOSPHORUS INSECTICIDES TO FISH, INSECTS AND MAMMALS †

Compound	*Fathead Minnows 96 Hr. TL_m‡ P.P.M.*	*House Fly (M. domestica) Topical LD_{50}§ Micrograms/Gram*	*White Rats Oral LD_{50} Milligrams/Kilogram*
EPN	0.20	1.9	12–40 §
Para-Oxon	0.33	0.5	3–3.5 §
Parathion	1.4	0.9	13.0 ¶
TEPP	1.7	. .	2.0 ¶
Chlorothion	3.2	16.5	880 §
Systox	3.6	. .	6.2 ¶
Methyl Parathion	8.3	1.0	14–42 §
Malathion	12.5	28	1,375 ¶
OMPA	121	. .	10 §
Dipterex	180	. .	630 ¶

† From Henderson and Pickering, 1958.
‡ Standardized conditions—soft water.
§ Values from Metcalf (1955).
¶ Values for male white rats under standardized conditions. From Technical Development Laboratories (1956).

Ten chlorinated hydrocarbon insecticides now being extensively used or proposed for large-scale operations were tested by means of bio-assays to determine their toxicity to fishes. Results of these studies which are summarized in Table II have been reported by Henderson, Pickering, and Tarzwell (in press). Two dilution waters representative of the hard and soft waters of the nation and four common warm water fishes were used in these studies. It was found that the water quality characteristics tested did not have much effect on the toxicity of the insecticides. Such differences as were obtained were not consistent for the different materials. Tests also were made to determine the relative toxicity to fish of different formulations. Emulsions and acetone solutions proved most toxic. In field tests carried out in the vicinity of Savannah, Georgia, during 1945 and 1946, it was found that the formulation (Tarzwell, 1947) of a mosquito larvicide influenced its toxicity to fishes and certain other aquatic forms. It was found that DDT dusts were less toxic than oil solutions which in turn were less toxic than emulsions when applied in a routine manner.

TABLE II †

COMPARATIVE TOXICITY OF CHLORINATED HYDROCARBON INSECTICIDES TO DIFFERENT SPECIES OF FISH ‡

	96 Hour TL_m (Median Tolerance Limit) P.P.B. (Micrograms/Liter) Active Agent			
Insecticide	*Fatheads*	*Bluegills*	*Goldfish*	*Guppies*
Aldrin	33	13	28	33
Dieldrin	16	7.9	37	22
Endrin	1.0	0.60	1.9	1.5
Chlordane	52	22	82	190
Heptachlor	94	19	230	107
Toxaphene	7.5	3.5	5.6	20
DDT	32	16	27	43
Methoxychlor	64	62	56	120
Lindane	62	77	152	138
BHC	2,300	790	2,300	21,700

† From Henderson, Pickering, and Tarzwell (In Press).
‡ Under standardized conditions—soft water as diluent. Temperature 25° C.

As indicated in Table II, endrin is the most toxic material to all fish tested. In fact it is more toxic to fishes than any material heretofore tested in the Center laboratories. All of these compounds other than BHC were toxic to fishes at concentrations less than 0.10 p.p.m. Bluegills were generally more sensitive to these materials than were the other fishes but there does not seem to be any definite relationships in regard to toxicity. One material may be more toxic to one species and less toxic to another.

With the exception of BHC, all the chlorinated hydrocarbons tested were significantly more toxic to fishes than were the organic phosphorus compounds. The toxicities of these materials as indicated by the 96 hour TL_m values are listed in Table III. These data show that the chlorinated hydrocarbon insecticides are much more important from the standpoint of potential harm to fish life than are the organic phosphorus compounds. In addition, their long lasting residual action makes them even more important as pollutants. Some of them remain toxic in the soil for considerable periods. Soil samples taken from treated cotton fields in the summer of 1950 were toxic to fish in November of that year. These studies (Doudoroff, Katz, and Tarzwell, 1953) showed that the insecticide used in these fields, Toxaphene, retains its toxicity for considerable periods, and is either not tied up in the soil and rendered nontoxic or the capacity of the soil to tie up the material was exceeded. That dieldrin also retains its toxicity in the soil has been shown by bio-assays of runoff from treated areas (Tarzwell and Henderson, 1957). It has been reported that dieldrin retains its toxicity in the soil for three or more years. These results contrast with other findings of the author in regard to DDT. In field investigations carried out in the vicinity of Savannah, Georgia, in 1945 and 1946, it was found that certain soils could adsorb or render nontoxic considerable amounts of DDT. Ponds having clay bottoms and considerable organic material seemed to have the ability to render DDT nontoxic. One such pond was treated with 0.1 lb. of DDT per acre 14 times without fish mortality while there was a fish kill in a sand bottom pond after 2 treatments at the rate of 0.05 lb. of DDT per acre. Thus, a fish kill occurred in the latter pond, even though it had received only one fourteenth as much DDT as the former pond in which there was no kill. One pond which received 18 weekly treatments at the rate of 0.1 lb. of DDT per acre was allowed to dry up and the surface layer of a measured portion of the bottom was taken for analysis. This bottom material when mixed in beakers containing mosquito larva had no insecticidal effect. However, it was found that this material contained DDT which totalled 0.82 lb. per acre. When these bottom materials were extracted with Xylene, the extracted material, added in very small amounts, was rapidly lethal to mosquito larvae.

TABLE III †

COMPARATIVE TOXICITY OF CHLORINATED HYDROCARBON AND ORGANIC PHOSPHORUS INSECTICIDES ‡

Chlorinated Hydrocarbon *Insecticide*	*96 Hour TL_m P.P.M. (mg/l) Active*	*Organic Phosphorus* *Insecticide*	*96 Hour TL_m§ P.P.M. (mg/l) Active*
Endrin	0.0013	EPN	0.25
Toxaphene	.0051	Para-Oxon	.25
Dieldrin	.016	TEPP	1.0
Aldrin	.028	Parathion	1.6
DDT	.034	Chlorothion	3.2
Methoxychlor	.035	Systox	4.2
Heptachlor	.056	Methyl Parathion	7.5
Lindane	.056	Malathion	12.5
Chlordane	.069	Dipterex	51
BHC	2.0	OMPA	135

† From Henderson, Pickering, and Tarzwell (In Press).
‡ Under standardized conditions—Fathead minnows in hard water. Temperature 25° C.
§ Values from Henderson and Pickering (1958).

Since most of the organic phosphorus compounds are readily hydrolyzed and may break down before reaching water courses, they probably do not constitute a serious threat to fish and other aquatic life, when used in the routine manner for terrestrial spraying. However, they appear to be more toxic to mammals than the chlorinated hydrocarbons. The comparative toxicities of the chlorinated hydrocarbon insecticides to fish, house flies, and rats are shown in Table IV. A comparison of this table with Table I will bring out the differences in toxicity of the organic phosphorus and the chlorinated hydrocarbon insecticides to fish and mammals.

TABLE IV †

COMPARATIVE TOXICITY OF CHLORINATED HYDROCARBON INSECTICIDES TO FISH, INSECTS AND MAMMALS

Insecticide	*Fathead Minnows ‡ 96 Hour TL_m (Milligrams/Liter)*	*Houseflies ¶ Topical LD_{50} (Micrograms/Gram)*	*White Rats Oral LD_{50} (Milligrams/ Kilogram)*
Endrin	.0013	. .	17.8 §
Toxaphene	.0051	31.0	90 §
Dieldrin	.016	1.1	46 §
Aldrin	.028	1.6	67 ¶
DDT	.034	8–21	113 §
Methoxychlor	.035	. .	6,000 ¶
Heptachlor	.056	1.6	100 §
Lindane	.056	1.0	125 ¶
Chlordane	.069	4.0	335 §
BHC	2.0	. .	1,000 ¶

† From Henderson, Pickering, and Tarzwell (In Press).
‡ Under standardized conditions—hard water. Temperature 25° C.
§ Male white rats under standardized conditions. From Technical Development Laboratories (1956).
¶ Values from Metcalf (1955).

Endrin, toxaphene, and dieldrin are extremely toxic to fishes, and even very small amounts can be damaging when applied to water surfaces. On the basis of laboratory bio-assay data, calculations have been made of the amount of each of the chlorinated hydrocarbon insecticides which would in 96 hours kill half the fish in an acre of water 3 feet deep (3 acre feet of water). These amounts are listed in Table V. It is apparent that very minute quantities are required; in the case of endrin only 0.005 lb. per surface acre.

It is emphasized that the TL_m values listed in Table V do not represent the amount per acre which is safe for aquatic life, but rather the amount which may kill 50 percent of the fish in 96 hours. What is desired is 100 percent survival under conditions of continuous exposure. To afford this protection the amount applied per acre probably would have to be considerably less than the 96 hr. TL_m values listed in Table V. The exact amount is not known but it would depend on several factors: among them inactivation, tie up in the soil, or transformation into nontoxic materials. It is apparent that several of these insecticides must not be applied to water surfaces at application rates generally used for insect control on land areas; namely, 1 to 2 lb./acre. Further, care must be used when treating by plane that these materials do not drift into water areas. Danger also exists that these materials will be washed from the soil and carried into ponds or streams in amounts which will be toxic to aquatic life. More research is needed before application rates or concentrations can be set up which are known to be safe for aquatic life. However, all control of the dispersal of these materials should not be held in abeyance until this information becomes available. Such a procedure could be disastrous for many organisms in the biota.

TABLE V †

AMOUNT OF CHLORINATED HYDROCARBON INSECTICIDE WHEN APPLIED TO WATER SURFACE THAT MAY PRODUCE FIFTY PERCENT FISH MORTALITY

Insecticide	*96 Hour TL_m P.P.B. (Micrograms/Liter) Active Agent* ‡	*Pounds Per Acre Applied to the Surface of Water 3 Feet Deep to Reach the TL_m Concentration*
Endrin	0.60	0.005
Toxaphene	3.5	0.03
Dieldrin	7.9	0.07
Aldrin	13	0.11
DDT	16	0.13
Heptachlor	19	0.16
Chlordane	22	0.18
Methoxychlor	62	0.51
Lindane	77	0.63
BHC	790	6.4

† From Henderson, Pickering, and Tarzwell (In Press).
‡ Under standardized conditions—bluegills in soft water. Temperature 25° C.

SUMMARY

Biological control based on a knowledge of the environmental requirements of the species to be controlled is generally the preferred and most economical means of control. If such methods are inadequate or too slow biological and chemical control methods can often be effectively combined.

When complete reliance is placed on control by the use of toxicants every effort should be made to use materials which are selectively toxic for the species to be controlled. Before toxicants are widely used their toxicity to other organisms in the biota should be determined. Further studies should be made to determine the smallest amount which is effective for the control of the pest species and to devise and use formulations, methods of application, and times of treatment which are least harmful to other organisms in the biota. In the extensive use of any pesticide, consideration should be given to its over-all pollutional potential such as its residual toxicity, its persistence in the soil, its contamination of surface runoff and seepage, and its effect on terrestrial and aquatic organisms.

When it is found that a selected pesticide is very toxic to other forms of life consideration should be given to the use of other materials which are not as toxic to other organisms in the biota even though they may be less effective for the control of the pest species. Data available elsewhere and the relative toxicities of organic phosphorus and chlorinated hydrocarbon compounds as indicated herewith, can serve to indicate materials which are not so harmful to aquatic life. In widespread spraying for the control of forest and agricultural pests it is believed that certain of the organic phosphorus compounds especially the

newer ones some of which are not very toxic to fishes, would be safer than most of the chlorinated hydrocarbons from the standpoint of aquatic life. This also applies to a newly developed carbamate.

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