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THE RISE AND FALL OF DDT

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ABSTRACT

DDT has had more influence on ecology than any other man-made substance. It has saved millions of lives and prevented more disease in human history than any other chemical, including penicillin. DDT together with other persistent chlorinated hydrocarbon insecticides has been strongly attacked as a contaminant of the environment. This article traces the history of DDT, its rapid rise, culminating with the award of the Nobel Prize in Medicine to Paul Mueller, the discoverer of the insecticidal properties of DDT, j and ending with the ban of DDT in most developed countries. An objective approach has been attempted to evaluate the advantages of DDT weighed against its disadvantages, with recommendations where its use should still be continued.

DDT has probably had a greater effect on reducing disease and hunger than any other man-made chemical substance. Nevertheless, after 20 years of extensive use a strong, sometimes highly emotional reaction against the use of DDT and other persistent organochlorine insecticides has started. This culminated in the banning of DDT in Sweden in 1969, the country which bestowed a Nobel prize on the discoverer of the insecticidal properties of DDT. Many other countries, including the USA and Canada, have also put most severe restrictions on its use. This article deals with the impact of DDT on

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[1] This paper was reviewed by Prof. E.D. Bergmann a short time before his death. He urged the authors to recommend the continued use of DDT more strongly than expressed in this paper. His opinions are presented in the inaugural lecture of the 2nd IUPAC Congress of Pesticide Chemistry at Tel-Aviv, 1971, reproduced in full in this volume.

health and agriculture and with the reasons which have changed attitudes towards this chemical.

Insects have been most important, often unwanted companions of man since earliest times. They threaten his health, food, fiber and dwellings. The Old Testament refers to insects ravaging crops and attacking man. The fate of the Crusaders' battles, Napoleon's invasion of Russia, the Crimean War and many other wars was influenced by insect-borne diseases. Between the 12th and the 18th centuries epidemics of black plague, typhus, cholera, yellow fever and malaria destroyed the population of entire cities and countries. Invasions of locusts brought famine to the Middle East and to many other parts of the world.

The oldest available record of the use of an insecticide is Homer's allusion to the use of sulfur. The toxic properties of arsenic were known to the Greeks and Chinese in the first Century. Tobacco powder was used against plant lice as early as 1860, and Darwin stated that "the dust of tobacco is frequently spread on affected leaves, but not I believe with very encouraging success, owing perhaps to the powder not being very fine, or not soon enough applied",

Large scale use of insecticides began with the application of "Paris green" (copper aceto-arsenite) to control the Colorado potato beetle in 1867. Prior to World War II the principle chemicals for insect control were arsenic and fluorine compounds, pyrethrum, rotenone, nicotine and petroleum oils. Arsenic and fluorine compounds are stomach poisons; insects must ingest them to be killed. Both are highly toxic to warm-blooded animals, and many cases of accidental death due to arsenicals were recorded. Pyrethrum kills insects by mere contact. It is practically non-toxic to man, but its high price and lack of residual effectivity limit its use. Numerous substitutes were synthesized and tested against insects due to the disadvantages of the available insecticides. Most of them did not become established because of a toxicity too high to man or too low to insects, high producton costs, phytotoxicity, corrosiveness or irritation to people.

In 1935 Paul Mueller began searching for new insecticides in his laboratories at J.R. Geigy A.G., Basle, Switzerland. He was looking for a compound possessing the following qualities, then considered ideal for an insecticide:

a. High toxicity against a broad spectrum of insects
b. Rapid onset of toxic action
c. Low toxicity against warm-blooded animals and plants
d. No unpleasant smell or other irritating effects
e. Persistent action, requiring few applications
f. Low cost.

Mueller began working with compounds containing two phenyl groups. After about 4 years he synthesized DDT and demonstrated its high contact toxicity against insects, and a Swiss patent for pest control purposes was claimed in March 1940 (Swiss Patent 226 180).

DDT or *D*ichloro*d*iphenyl*t*richloroethane, or more correctly 1,1-bis-(p-chlorophenyl)-2,2,2-trichloroethane, had been synthesized many years earlier by Othmar Zeidler at the University of Strasbourg. His work was published together with studies of other students of Adolph von Baeyer (1874). Zeidler later owned a pharmacy in Vienna, and died in 1911 without ever recognizing the importance of the substance he had synthesized.

DDT is a white to cream-colored powder, practically insoluble in water and stable at temperatures up to 100°C. DDT is dehydrochlorinated in the presence of alkali to form DDE (1,1-bis-(p-chlorophenyl)-2,2-dichloroethylene), a compound even more stable than DDT. DDT applied indoors may remain effective up to a year, losing its effect only when covered by accumulations of grease and dirt; in field conditions with maximum surface exposure it slowly decomposes under the influence of solar ultraviolet irradiation.

In spite of 30 years of intensive research, the mode of action of DDT is not fully understood. It primarily affects the nervous system, especially the sensory nerves, both in insects and vertebrates. DDT enhances the action potentials of neurons by changing the potassium permeability of nerve membranes. The poisoned nerves repetitively discharge and throw the muscles into tremors, the "DDT jitters", and finally lock the muscles in a tetanic paralysis.

DDT, compared to other insecticides, is only moderately toxic to warm-blooded animals (Table 1). The oral LD_{50} is in the range of 120-300 mg/kg. The symptoms of acute poisoning in mammals result from disturbances of the central nervous system. They include overexcitability, tremors, convulsions and paralysis (Hayes, 1959). Rats kept on diets containing 5-10 ppm DDT had microscopic changes in their liver cells. Human responses to various DDT dosages are presented in Table 2.

TABLE 1: ACUTE ORAL TOXICITIES OF PAST AND PRESENT LEADING INSECTICIDES

Compound	LD_{50} for rats in mg/kg
lead arsenate	10-100
Paris green	22
DDT	118-300
dieldrin	40
parathion	3-6
malathion	1400-2800
propoxur (carbamate)	80-100

TABLE 2: DOSAGE-RESPONSE OF DDT IN MAN

Dosage (mg/kg/day)	Remarks
Unknown	Fatal
16-286	prompt vomiting at the high doses (all poisoned, convulsions in some)
10	moderate poisoning in some
6	moderate poisoning in one man
0,5	tolerated by volunteers for 21 months
0.5	tolerated by workers in DDT factories for 6½ years
0.25	tolerated by workers in DDT factories for 19 years
0.004	dosage of population in Delhi area, India, 1964 - combined intake from living in sprayed houses and from food
0.0025	dosage of general population of USA, 1953-54
0.0004	dosage of general population of USA, 1963-67

Data from: Official Records of the World Health Organization No. 190, April 1971.

DDT is highly soluble in fatty materials resulting in its storage in animal fats and its subsequent appearance in milk. This poses a special danger to infants as their principle food is milk, hence the usage of DDT on fodder crops was already forbidden in the early '50's. Human milk now contains more DDT than cow's milk. Levels of DDT in human milk are about 0.1 ppm in the USA, and have not changed essentially during 20 years of DDT-usage. Breast-fed babies receive about 0.02 mg DDT per kg of body weight, which is twice the permissible dose set by the World Health Organization. A recent study showed that also in Germany almost all samples of mother's milk assayed possessed higher than permissible doses of DDT (Rappl and Waiblinger, 1975).

The deposition of DDT in fatty tissues depends on its daily intake. As the dosage increases, fat storage increases (Mrak, 1969), though at a progressively declining rate. When one loses weight, DDT is released from the fatty tissues into the blood stream and can exert its toxic effects. Some ingested DDT is metabolized to water-soluble DDA (p,p'-Dichlorodiphenylacetic acid) (Fig. 1), which is excreted in the urine.

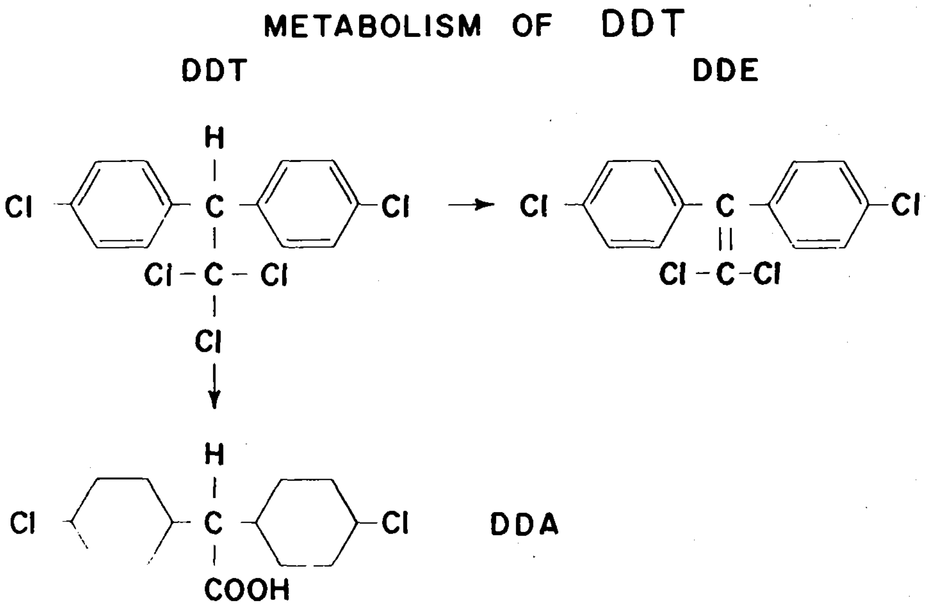

Fig. 1

DDE is the major metabolic produce of DDT in insects, especially resistant species, some bacteria and birds. In vertebrates DDT is converted to DDE and also to DDA which is water-soluble and excreted in the urine.

Since DDT is efficiently absorbed through the insect cuticle and tarsi, it was possible for the first time to kill disease-carrying flying insects not reached by the oral poisons used hitherto. DDT is also an effective stomach poison against insects feeding on treated leaves, as it is absorbed through the gut.

DDT was initially used against insect vectors of human diseases. It appeared on the public health scene during World War II in Naples and dramatically halted a typhus epidemic, a rickettsial disease transmitted by body lice. Whenever people are crowded together, especially in time of war, this disease becomes rampant, reaching its peak during winter and spring. Millions died of typhus during World War I. Typhus again threatened during World War II. Over 80,000 cases were recorded in North Africa. The disease was common in the Balkans, Russia, Italy and in German concentration camps. When the Allied Forces landed in Italy in 1943, a typhus epidemic was engulfing Naples, a city of nearly a million living in insanitary congested conditions with little food. The methods of delousing practiced prior to World War II were cumbersome and expensive, and recently-deloused people were subject to reinfestation. The best delousing dust contained pyrethrum and 2,4-dinitroanisole, and was applied by puffing dust all over the body. This powder controlled lice for one week only. At a time when millions had to be powdered weekly the Allies were cut off form the sources of pyrethrum in Japan. The newly developed Swiss louse powder "Neocide" (5% DDT in talc) was a godsend. The entire population of Naples was dusted and the typhus epidemic was stopped within 3 weeks. A typhus outbreak was controlled in winter for the first time in history (Simmons, 1959).

Malaria, the most important disease of man, was controlled until World War II by costly methods of water management and using "Paris green" as a mosquito larvicide. Weeks or months of intensive effort were required to achieve a substantial reduction in the spread of the disease. These slow methods were of no use to protect troops invading malarial areas. The total output of DDT during World War II was allotted to the military for the control of insect vectors of human diseases. Aerial sprays of DDT were tested for the first time in 1943 and almost immediately solved the military malaria problem. Churchill in a parliamentary speech in September 1944 drew world-wide attention to the astonishing results obtained by the use of DDT and stressed its importance to the Burma and the Pacific War theaters where malaria was dominant.

DDT brought about radical changes in the method of malaria control. The insecticide persisted on inside walls for many months after application. Its relative safety to man and its low cost provided an economic method of malaria control for the first time. Reports from Greece, Italy, Venezuela and elsewhere indicated that the residual effect of DDT was the reason for the complete cessation of malaria in endemic areas.

A worldwide program of malaria eradication, based on the use of persistent insecticides, was initiated by the World Health Organization (WHO) in 1955. Over a billion people now live in areas freed of malaria (WHO, 1971). The striking reduction in mortality rates in some countries where malaria eradication was mainly based on DDT is presented in Table 3.

Tsetse flies are the vectors of African trypanosomyasis in man and livestock. The commanding place of cattle in African society gives a special importance to a disease responsible for abandoning large areas of good pasture. Fly control is dependent mainly on insecticides, with DDT again at the forefront.

Blackflies breed in rapidly running water and transmit the filarial worm *Onchocerca* which causes blindness. Onchocerciasis is widespread in Africa, Central and South America. DDT made the control of larvae of these flies practical. When it is sprayed or poured into a stream, it disperses through the breeding habitat and remains effective for a long time and a long distance beyond the point of application, This effect of DDT was very well demonstrated in Kenya, where children born after 1946 are free from onchocerciasis while before the advent of DDT more than 70% were infected. In the 1950's DDT was applied to thousands of miles of rivers in tropical Africa, USA, Canada, Mexico and Japan.

Fleas transmit the organism causing bubonic plague and murine endemic typhus from rats to man. Fleas are most important in the transmission of murine typhus in the southern USA and of plague in the western USA. The methods of controlling fleas were not satisfactory before the use of DDT, as public health authorities could only fight the disease by eradicating rats. The immediate effect was an increase in the number of people bitten by insects deprived of their rodent hosts. Rat fleas were effectively controlled by applying dust in buildings, runways, holes and other places where rats hide. DDT drastically reduced endemic typhus in the southern USA.

TABLE 3

CHANGES IN MALARIA MORBIDITY IN COUNTRIES BEFORE AND AFTER MALARIA WAS CONTROLLED OR ERADICATED

Africa	1948	46.395 cases
Mauritius	1969	17 cases
The Americas	1962	3.519 cases
Cuba	1969	3 cases
Dominica	1950	1.825 cases
	1969	Nil
Dominican	1950	17.310 cases
Republic	1968	21 cases
Grenada and	1951	3.233 cases
Carriacou	1969	Nil
Jamaica	1954	4.417 cases
	1969	Nil
Trinidad and	1950	5.098 cases
Tobago	1969	5 cases
Venezuela	1943	817.115 cases
	1958	800 cases
South-East Asia	1935	over 1.000.000 cases
India	1969	286.962 cases
Europe		
Bulgaria	1946	144.631 cases
	1969	10 cases
Italy	1945	411.602 cases
	1968	37 cases
Romania	1948	338.198 cases
	1969	4 cases
Spain	1950	19.644 cases
	1969	28 cases
Turkey	1950	1.188.969 cases
	1969	2.173 cases
Yugoslavia	1937	169.545 cases
	1969	15 cases
Western Pacific	1945	over 1.000.000 cases
China (Taiwan)	1969	9 cases

Data from: Official Records of the World Health Organization No. 190, April 1971.

We have presented only a few important cases where DDT made medical history. These dramatic achievements, based on the discovery of the great efficiency of DDT as a residual contact insecticide, earned Paul Mueller the 1948 Nobel prize in medicine. DDT has probably saved tens of millions of human lives and prevented more than a billion human illnesses (Knipling, 1953). The early successes made people believe that epidemics of typhus, malaria and plague were a thing of the past, and that DDT would permanently abolish all insect-borne diseases.

DDT was released to the civilian market after World War II, and extensive experiments were carried out around the world to control all agricultural pests. DDT was particularly effective in destroying many caterpillars, beetles, leafhoppers and plant bugs that infest garden and field crops. It controlled Colorado potato beetles, Japanese beetles, codling moths, oriental fruit moths and gypsy moths. In spite of this wide spectrum it was not effective enough against ticks, Mexican bean beetles, boll weevils, cotton leafworms, aphids and spider mites, but often killed some of their natural enemies including predatory ladybird beetles and parasitic wasps. As a result, it sometimes happened that following application of DDT to control one economic pest, other pests which had been of lesser importance suddenly proliferated. These formerly minor pests may cause more damage than the primary pest controlled by DDT.

Control of agricultural and medical pests consumed large amounts of DDT in the 1950's and 60's. The use of DDT rose steadily reaching a peak in 1964 due to the global malaria eradication program. Production since 1970 has dropped severely due to the availability of other synthetic insecticides and to the trend to restrict the use of persistent chemicals.

Only a few years after the introduction of DDT, reports appeared of its failure to suppress insect populations which it formerly controlled. These failures were first observed with houseflies (Sweden, Italy, and Denmark in 1946) and with mosquitoes (Italy, 1947) (Brown and Pal, 1971). Faulty equipment, formulations or application were first blamed, but careful laboratory tests revealed that the insects had become resistant. Dosages which formerly killed all insects became ineffective, and even 3 to 10 fold increases in the DDT concentration did not control some resistant populations. More than 220 economically important insect species are now known to be DDT resistant, some over widespread areas.

DDT resistance had its greatest impact on the malaria eradication campaign (Busvine and Pal, 1969). Severe epidemics of malaria followed the appearance of DDT resistant mosquitoes in Greece, Iraq, Venezuela, Iran and India. Due to the development of DDT resistance the eradication of yellow-fever mosquitoes *(Aedes aegypti)* was not attained in the Carribean and in the northern parts of South America. After the dramatic success of DDT in controlling typhus epidemics during World War II the advent of DDT-resistant body lice during the Korean War was unexpected. Control was only achieved by the use of alternative compounds. The incidence of plague rose in Vietnam after 1962 because of the failure of DDT to control rat fleas.

DDT resistance is an inherited trait selected for from within a population normally susceptible to DDT. The main physiological mechanism of DDT resistance is the ability of resistant insects to metabolize DDT to the noninsecticidal DDE (Fig. 1). This detoxification is carried out by the enzyme DDT dehydrochlorinase, which removes hydrochloride (HCl) from the DDT molecule.

The appearance of DDT resistance in an increasing number of insects cast the first shadow on the concept that DDT was the long sought panacea for insect control. A major blow to DDT was the publication of "Silent Spring" by Rachel Carson (1962). Miss Carson charged that insecticides were poisonous not only to insects but also to birds, fish, wildlife and to man himself, at levels of toxicity previously deemed to be only minor drawbacks considering the tremendous benefits of DDT.

Charges of immediate human toxicity are not substantiated by the high safety record of DDT. Millions of people have had 10% DDT powder blown into their clothing as they wore it, or have had the walls of their homes sprayed year after year. DDT has been added directly to drinking water for control of yellow fever mosquitoes. Many plants and animals have been sprayed with this insecticide and then eaten by man. Yet, in spite of this prolonged exposure of the world population to DDT, the only confirmed cases of acute injury have been the result of massive accidental or suicidal ingestion. Rachel Carson emphasized the inherent possibilities of a cumulative effect of DDT or a persistent byproduct. As a result, research on various facets of possible injurious effects of DDT was intensified.

As yet there is no clearcut evidence incriminating DDT as carcinogenic to humans. The Bionetics Research Laboratories studied the carcinogenic potential of a number of synthetic compounds including DDT. DDT increased the incidence of cancer in mice, however the dose rate used was over 100,000 times greater than that obtained in an average diet. Furthermore, the study was undertaken with a strain of mice in which spontaneous cancer is common. The International Agency for Research on Cancer at Lyons reconfirmed these findings using lower doses, but only hepatomas were observed, never malignant tumors. Penicillin-G and isoniazide in use as human drugs for many years have also produced tumors in mice. Thus the significance of all these findings is not yet clear (Devlin, 1974).

Tests in mice to determine whether DDT produced dominant lethal mutations proved negative. Conversely, treatment with extremely high doses such as 100 to 400 mg DDT per kg body weight caused chromosomal aberrations in mice (Johnson and Jalal, 1973).

A large amount of experimental work has been published on the activity of DDT and its interaction with body metabolites. When administered to rats, DDT enhanced the levels of hydroxylating enzymes in liver microsomes, that metabolize drugs and steroids. This stimulation may be the cause of lowered fertility in animals suffering from DDT poisoning.

Every person sampled in recent years in Europe, Asia, Africa, Australia and the Americas had a trace of DDT in blood and every other tissue (Table 2) with higher concentrations being found in tropical countries (Maier-Bode, 1968), but even Eskimos showed 3 ppm of DDT and DDE in their body fat (Durham, 1969). Some of the earlier data in the literature should be treated with reservations since they did not distinguish between polychlorinated biphenyls and DDT in the chromatographic peaks. Polychlorinated biphenyls have recently been incriminated as important pollutants showing numerous toxic side effects. It is therefore too soon to assess the contribution, if any, of environmental contamination by DDT to cancer, reduction in fertility or genetic changes in man.

The ultimate toxicity of DDT to certain forms of wildlife is beyond doubt. The presence of DDT in the environment during the past 25 years was claimed to produce two serious effects. The first is the reduction and contamination of fishery products from streams, lakes and offshore areas (Edwards, 1970). The second is the progressive extermination of certain species of predatory birds and beneficial insects.

Extremely low concentrations of DDT kill crustaceans; higher concentrations kill fish, and terrestrial vertebrates at yet much higher dosages. DDT accumulation in fish can kill their embryos. Fishes amass DDT by eating aquatic plants which have absorbed it and incorporate it directly from the water, probably through their gills. DDT levels in fish rarely exceed a few parts per million (Edwards, 1970) except when they have been subjected to larger than usual doses. This has occurred in Lake Michigan where the levels have been high enough to condemn fish as unfit for human consumption (Harrison *et al.*, 1970). Generally, there are higher levels of DDT in fresh water fish than in sea fish, because of the enormous dilution of the DDT upon reaching the sea.

The accumulation of DDT in food webs has proved to be more important than direct exposure (Eichler, 1969). The DDT present in lower forms of life: bacteria, insects, worms, slugs, plankton and algae, is passed on and often concentrated as it goes up the food web (Woodwell *et al.*, 1967). Birds, near the apex of the food web, especially those that prey on fish and other birds, have suffered grievously from accumulation (Robinson, 1967). From the standpoint of nature conservation the problem has become acute. Certain hawks and eagles are progressively disappearing because their eggs do not hatch. It has, however, been reported that some preying birds showed severe population decline well before the introduction of DDT.

Mechanism of eggshell thinning may be attributed to the fact that DDT and other chlorinated hydrocarbon insecticides stimulate hepatic microsomal enzymes (Kupfer, 1967) that should then (Devlin, 1974)

1) degrade steroid hormones essential for calcification,

2) inhibit medullary bond deposition which is the main source of calcium during shell formation,

3) inhibit carbonic anhydrase activity in the avian shell gland that provides the carbonate ions necessary for the calcium carbonate deposition.

A high DDE content in eggs is correlated with the production of thin shells and hence with a failure to hatch (Peakall *et al.*, 1975). Man and domestic animals are protected by legal requirements which specify definite time intervals between insecticide application and harvest or consumption of crops. Wildlife can hardly be expected to avail itself of such precautions.

The strongest argument to discontinue the use of DDT is based on its persistence in nature. This property, which made DDT an excellent residual insecticide, also caused it to linger and build up in the environment as well as in body fat. When Mueller was looking for an ideal insecticide, one of the most important attributes was persistent action. We are now progressively becoming aware of the dangers of environmental pollution, and persistence has become a curse. An ideal pesticide should be degraded and disappear from the environment after its action on the target organism.

DDT is relatively indestructible (Menzie, 1972). The world pattern of movement of DDT residues is from the land through the atmosphere and rivers into the oceans. Part of it sediments below the thermocline into the lower abyss of water that remains unmixed, where it probably will persist intact for hundreds of years. A smaller part is selectively absorbed by the plankton, being carried from there further up the food web (Woodwell *et al.*, 1971).

Agricultural soils in the USA contain an average of 0.17 grams of DDT per square meter (Pimentel, 1973). The greatest residues are found in orchards, vineyards and vegetable gardens. DDT remains in the top layer of the soil even after intensive irrigation, because of its insolubility in water. The use of DDT in the USA and many European countries has been severely restricted from the beginning of the decade, but existing residues will remain in the food cycle for many years, presenting a hazard to many forms of life, especially carnivorous and scavenging birds and fishes.

Quantitative date for traces of DDT in the environment should be treated with some reservations. Soil samples sealed in containers in 1910 were recently analyzed at the University of Wisconsin. Trace amounts of organochlorine pesticides were detected although these compounds were not used before the 1940's (Devlin, 1974).

In view of the harm caused by DDT we must ask ourselves if DDT should be banned globally. Had this question been posed in the early '50's the answer would have been a resounding No. At that time our arsenal of insecticides contained nothing approaching the effectiveness of DDT. Subsequently a great variety of chlorinated hydrocarbons, organic phosphates, as well as carbamates have been developed, some of which are outstanding insecticides of low persistency. The use of dieldrin, aldrin, heptachlor and other organochlorine compounds has recently been banned in the USA because of suspected carcinogenic hazards. Other compounds are either too toxic, or uneconomically priced, or too costly because of the need of repeated applications. The cost advantage of DDT over malathion (an organic phosphate) and propoxur (a carbamate) which both have low persistence and are highly efficient in malaria control is shown in Table 4.

TABLE 4

COMPARATIVE COST OF MALARIA CONTROL
BY 3 CHEMICALS PER MILLION POPULATION

Insecticide	Approx. duration of residual effect in months	Metric tons required	Approx. cost/ metric ton in dollars	Cost of application in US $	Total cost	Cost Ratio DDT=1
DDT 75 %	6	133	1000	150.000	283.000	1
Malathion 50 %	3	400	1580	300.000	932.000	3.3
Propoxur	3	400	5000	300.000	2.300.000	8.1

Data extracted from Official Records of the World Health Organization No. 190, April 71, and updated according to prices provided by WHO, May 1976.

Forty-eight of 110 developing countries still list malaria as a major health concern with filariasis, another mosquito-borne disease, stressed in 11 countries. The replacement of DDT in the global malaria eradication program would increase the present cost estimated at $ 85 million, to approximately $ 280 million if malathion were substituted, or to $ 690 million if propoxur were to replace DDT. Withdrawal of DDT without any substitutes leads to calamities. In Ceylon malaria had been reduced to very low levels and the stoppage of DDT spraying operations brought about new epidemics with a total of over 2½ million reported malaria cases during 1968 and 1969 (Table 5): In India, in areas with a population of over 90 million where malaria had become a memory, house spraying had to be reintroduced owing to the resurgence of the disease.

TABLE 5

THE EFFECT OF DDT ON MALARIAL CONTROL IN CEYLON

Year	No. of cases of malaria	Remarks
1946	2.768.385	
1950	610.781	DDT introduced
1954	29.650	
1958	1.037	
1962	31	
1964	150	spraying withdrawn
1966	499	
1968	over 1.000.000 (estimated)	440.644 positive out of 1.681.052 examined
1969	over 1.000.000 (estimated)	537.705 positive out of 1.446.467 examined
1970		468.199 positive out of 1.500.307 examind
1971		145.368 positive out of 1.371.475 examined
		implementation of large scale control measures
1972		132.605 positive out of 1.545.700 examined

The true incidence for the years after 1967 is not known.

Data from World Health Organization.

Presently available funds of the World Health Organization are insufficient to pay for DDT substitutes, therefore the WHO very sensibly recommends the continued use of DDT for indoor spraying to control malaria mosquitoes and indoor dusting for plague fleas and typhus lice, rather than risk another outbreak of these diseases. Still the WHO recommends restricting all outdoor uses, especially application to water. Accordingly, blackflies, which require insecticide applications to fast running waters, must be exterminated by degradable chemicals. Such compounds are too expensive for most developing countries, yet people are not willing to suffer onchocerciasis, just to keep international waters clean. In our opinion, the extra cost involved in replacing DDT should be borne by the world community through international agencies.

The use of DDT against agricultural pests ought to be restricted. This would not lead to a major catastrophe, at least in the USA. Only about 5% of the total crop area in the USA received insecticidal applications (Pimentel, 1973). Of the food crops, corn, fruit and vegetables receive the largest amount of insecticide. Control of the cotton boll weevil, the cotton bollworm and the codling moth accounts for 40% of all the insecticides used in the USA. DDT was never effective against the boll weevil and non-persistent insecticides are available to replace its use for the other pests, though some may cause environmental problems of their own.

Crop losses due to insects were about $ 3.9 billion annually in the USA in the early 1960's or 13% of the total crop. An additional loss of $ 1 billion would occur if the 5% of the crop acreage receiving insecticides was left untreated. This would still leave an ample food supply, but certain fruits and vegetables, such as apples, peaches, plums, onions and potatoes could not be grown. People must be prepared to buy oranges with severly blemished peels and cabbages with insect caused holes in the outer leaves. The affluent society may be willing to pay such a price for a pesticide free environment. On the other hand some developing countries may not be able to afford this price. The Green Revolution was based on new strains of high-yield grains and heavy use of fertilizers and pesticides. Peace Nobel Laureate E. Borlaug (1973), in a speech at the Food and Agricultural Organization of the United Nations, stressed that without the use of DDT, advantages achieved by the Green Revolution would become lost. We believe that each country should have the right to determine its own standard of environmental pollution balanced against hunger and disease. Should pollution spread over borders, then international agencies will have to bear the cost of alternative control methods.

Public pressure following the impact of "Silent Spring" brought about intensified research on non-insecticidal control methods. Parasites, predators or pathogens to destroy harmful insects, sanitation, development of insect resistant crop plants, introduction of sterile male insects to reduce reproduction, use of sex attractants to prevent mating, or species–specific juvenile hormone analogues to interfere with normal development are among the methods currently being investigated.

Some of the biological methods have already been applied to a few specific insects for many years, but none are universal. Universality though economically advantageous is no longer an attribute; specificity has become the desirable trait for control methods. Unfortunately, biological and genetic methods take a long time to develop and years may elapse before such controls will obtain widespread use. We believe that an integrated approach, combining various biological with selective chemical methods will ultimately be used to protect man and his food from insect damage.

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