PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Pesticides for Locust Control [and Discussion]

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Pesticides for locust control

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The factors influencing the choice of insecticides for locust control are effectiveness, safety in use, relative cost, and the formulations available. The relative importance of these factors varies with the scale of control. In small scale control by farmers safety and simplicity are paramount and a BHC dust is commonly used, but in large scale control operations by specialized organizations more toxic formulations ultra-low-volume (u.l.v.) concentrates and methods of application requiring considerable skills can be used. The remarkable effectiveness of dieldrin as a stomach poison appears to be due to its conversion to photodieldrin after application. Cases of poisoning following large scale control operations are rare, and fatalities in man unknown. Alternatives to organochlorine insecticides include fenitrothion, already recommended and used on a large scale against adults. Against nymphs the correct dosage of fenitrothion would cost nearly 11 times as much as that of dieldrin. Recent experimental work with new insecticides has included safety tests with domestic animals and measurements of persistence. 1 μg deposits of cyanofenphos, decamethrin and mecarphon, as well as of dieldrin and photodieldrin, on wheat seedlings left in the open under tropical conditions for two days, killed 80 % or more first instar nymphs of the Desert Locust which fed on them.

1. Introduction

Whether a pesticide formulation is used for killing locusts depends on its properties which in turn determine how it can best be applied. Modern locust control methods, based on spraying oil solutions of insecticides, may be regarded as starting from the aerial spraying trials carried out in the 1940s in Kenya and Tanganyika (Gunn 1948) although aircraft were used to apply poison dusts against locusts much earlier.

2. Factors influencing choice of insecticides

Effectiveness, safety, cost and the suitability of formulations are the factors which influence the use of an insecticide on a large scale. Two other factors should also be mentioned here, resistance and persistence. The development of resistance to a pesticide is regarded as the normal response of an insect population to the selection pressures applied by the continuous use of insecticides. I do not think that any naturally occurring population of the Desert Locust, *Schistocerca gregaria* (Forsk.), has ever been exposed to continuous selection pressure by insecticides over several generations. Given an adequate exposure to insecticides locusts would also develop resistance quite rapidly. Even within the fairly inbred stocks of locusts reared at the Anti-Locust Research Centre during the 1950s the doses of insecticides estimated to yield a 50 % mortality (l.d.$_{50}$) could vary by as much as five times between nymphs from different egg pods (MacCuaig 1968). In other laboratory experiments Shafi (1973) showed that resistance could be developed easily to both γBHC and fenitrothion. One aspect of resistance is the development of cross-resistance, that is the development of resistance to insecticides other than

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the one producing the selection pressure. Shafi's results showed that there was some cross-resistance developed. The development of cross-resistance depends on the mechanism of resistance involved: it is mentioned here as a possibility of the insecticide-insect interaction which might become important.

The so-called persistent insecticides are those which are only slowly broken down after application and which, at least until the early 1960s, were manufactured and applied at a world-wide rate greater than their rate of breakdown so that there was a world-wide accumulation of these materials up to an estimated 50000 t of DDT circulating in the atmosphere in the late 1960s (Ling, Whittemore & Turtle 1972). Three aspects of persistence are of concern here, the duration of toxic effects at the site of application, the persistence of the material beyond the time required for its insecticidal action to be completed and its possible addition to the world-wide occurrence of the material. After a 'persistent' insecticide is applied most of it is usually quite rapidly lost from the site of application, depending on its properties and where it was applied. Even in the United Kingdom loss of DDT from the soil by evaporation is the most important factor (Lloyd-Jones 1971) and in tropical climates must be greater. In one study an experimental area of about 1400 ha was selectively treated with dieldrin for control of tsetse flies and a careful study made of the fate of the applied dieldrin. Air samples were taken and from a consideration of the concentration of dieldrin found, the size of the area involved and the winds during the period of observation, it was estimated that up to 20% of the dieldrin had volatilized within one month of application (Koeman *et al.* 1971). Vapour pressure often appears to be much less important in affecting volatility than might be expected. For example dieldrin evaporated from a soil surface more rapidly than diazinon although the vapour pressure of diazinon is 100 or more times greater than that of dieldrin (Lichtenstein & Schulz 1970).

3. Scale of locust control operations

Locust control operations can be carried out at several levels and it is convenient to term these small, medium and large scale operations. Small scale operations are those carried out by the farmer to protect his own crops. In the more developed countries it is usually mandatory for the farmer to take some action towards killing the locusts on his own land, with or without Government assistance, but in poorly developed countries control can only be done if the Government supplies insecticides and sometimes also spray equipment. Baiting, that is, applying the insecticide in a carrier to be eaten by the locusts, or dusting are the simplest methods for use at this level. Special application machinery is not necessary, the insecticides usually being distributed by hand. Thus the prime requirement is for safety, so that the farmer can use the insecticide formulation at virtually no risk to himself, his family or his stock. Control personnel in general like to see the insects dying quickly after treatment but rapid action is especially important following operations by poorly educated farmers so as to avoid excessive overdosing and consequent wastage of insecticide. γBHC meets these requirements better than other insecticides and is the principal one used. Concentrations of about 1 g of actual insecticide per kilogram bait are usual, while in dusts it is used in concentrations of 20–30 g kg^{-1}.

Medium scale operations carried out by Governments are usually an attempt to destroy the locusts in the country or to kill them on entry. In addition to helping farmers directly it will include ground and perhaps aerial spraying operations. Special staff are often employed for this work or they may be part of the general Plant Protection Organization of the country. Inasmuch as specialized staff and equipment are used, medium scale control operations merge into large scale operations where the objective is to reduce the locust population in a whole region. This is normally carried out by a completely specialized and sophisticated organization devoted at least primarily to this work. Where competent staff and specialized equipment are available the limiting requirements have a different emphasis. More hazardous formulations and methods of application requiring considerable skills can be used. Various types of formulations, baits, dusts or sprays could also be applied. All have been used on a large scale but spraying has been found to be the most reliable and economical.

(*a*) *Insecticide formulations*

A DNC formulation was the first to be used in routine spraying operations on a large scale in eastern and central Africa. The formulation finally used was devised at the Chemical Defence Experimental Establishment, England, where particular attention was given to obtaining a high concentration of this quick acting insecticide (200 g l^{-1}) in a stable solution with a low volatile solvent. Although the best available at the time this insecticide suffered several disadvantages. It is especially hazardous to use (man seems to be more susceptible than most test animals). Although DNC is rapid in its action against locusts it is also detoxified quite quickly so that successive sprayings may not be fully cumulative in their action. This formulation was soon replaced by a crude BHC solution (containing 150 g l^{-1} of γ isomer as the insecticidally active constituent) originally made as a wood preservative. Many hundreds of thousands of litres of this and similar formulations have since been applied. At about the same time the insecticide dieldrin started to be used for locust control. Dieldrin was first used against grasshoppers in the late 1940s and its use continued until the extent of its persistence in the environment was realized. Against locusts in developing countries however it has continued to be used and a greater area in Africa has probably been sprayed with dieldrin formulations than with all other insecticides together. One estimate suggests that nearly 80 % of the liquid insecticides used were dieldrin formulations and the area which could be treated with dieldrin comprised over 90 % of the total treated by all insecticides during a three year period between 1972 and 1976 (MacCuaig, in preparation). It is the properties of dieldrin allowing its use as a persistent stomach poison which are unique. Field trials and use on a large scale have shown that doses of even less than 10 g ha^{-1} can, when properly applied under some conditions, be lethal to locust nymphs when feeding in sprayed areas. This startling effectiveness appears to be due partly to its innate toxicity and partly to its conversion to a photoisomerization product (photodieldrin), which is more toxic and persistent than dieldrin itself, and the availability of a good formulation. Dieldrin is one of the most toxic compounds known against locusts with mean $l.d._{50}$ less than 1 $\mu g\ g^{-1}$ against first instar nymphs and less than 2 $\mu g\ g^{-1}$ against fifths. After application dieldrin may be quite quickly converted to photodieldrin in strong sunlight. A detailed study showed that 6 days after large scale spraying the total residues had fallen to about two thirds of their initial value and that most of the remaining residue was photodieldrin (Wiese, Basson & Van der Merwe 1970). Photodieldrin is also more toxic to mammals generally but when domestic animals were exposed to deposits of dieldrin and photodieldrin their tissues and milk contained less photodieldrin than dieldrin even though the deposits were mostly comprised of photodieldrin. Physically the dieldrin formulation developed specially for locust control, Ensodil 20, has a negligible evaporation rate due to its high boiling range solvents and a low viscosity which make it an ideal solution for ultra-low-volume spraying. Below 10 °C there may be some crystallization of dieldrin: but this is unlikely to occur in most of the areas where Ensodil is stored, and in any case the sediments normally redissolve on warming above 10 °C. The solution was developed for the Exhaust Nozzle Sprayer (Sayer 1959) with no moving parts, powered by the vehicle's exhaust gases and producing a droplet spectrum of volume median diameter about 70 μm, which can be said to have revolutionized locust control as large scale operations could be carried out cheaply by most locust control or plant protection organizations. Similarly the development of rotary atomizers for aircraft, producing volume median diameters of spray droplets around 100 μm at low spray pressures, enabled those organizations operating aircraft to carry out control operations at an extremely rapid rate.

4. Safety

The mortality record in locust control operations is very good considering the difficult conditions of operating and the perpetual shortage of vehicles which sometimes results in the same vehicle being used to carry insecticides and personal effects including food. At the end of the last plague of the Desert Locust FAO sent out a questionnaire on the use of insecticides for locust control to plant protection departments and locust control organizations in the countries concerned. The replies indicated that there were occasional instances of poisoning, particularly amongst stock, but that there were no human fatalities. The use of parathion-methyl, as might be expected from its high mammalian toxicity, resulted in low blood-cholinesterase levels amongst some control personnel and five people were hospitalized in Pakistan (MacCuaig 1966). In eastern Africa over 300000 l of DNC (200 g l^{-1}) were sprayed before the use of this material was stopped. This insecticide can be detected directly in the blood and out of 234 such tests only 19 were excessively high (Rainey 1958). The narrow margin between effective use of dieldrin and mortality of domestic animals was shown by spraying operations which as well as being some of the most successful undertaken against locusts also resulted in the death of some stock. On a small scale, goats living in a plant protection compound where no insecticide had been stored for some years absorbed near lethal amounts of dieldrin in 10 days. This led to serious concern about the dieldrin levels in the blood of staff working in the same compound for years. A detailed study was undertaken to determine blood levels of BHC and dieldrin in all the staff of the DLCOEA. This showed only low levels of these insecticides but levels of *p,p′*-DDT and *p,p′*-DDE were high, owing either to the use of DDT against other pests or to its domestic use (MacCuaig 1976). These tests suggested that although the situation in a non-plague period was satisfactory, safety precautions were probably not adequate to allow for the degree of continued and extensive exposure to these insecticides which control staff are likely to experience during a arge scale locust control campaign.

5. Costs

A knowledge of price is of course a vital factor affecting the choice of an insecticide. Only during a plague are the costs of insecticides an important part of the operating budget of a locust survey and control organization. In large-scale operations Rainey (1954) estimated that insecticide costs were only about one third of the total costs of application of a BHC solution. Use of fenitrothion would increase the proportion of insecticide costs and in small intensive operations in Australia insecticide costs were about two thirds of the total cost of application. World

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

insecticide prices have risen dramatically in the last few years: prices of some individual products rising to as much as four times their 1973 prices (FAO 1976). Insecticides used for locust control were not affected quite as much, but the price of Ensodil 20 increased by 2.3 times between 1971 and 1976, while that of technical fenitrothion increased by 2.5 times between 1971 and the end of 1974.

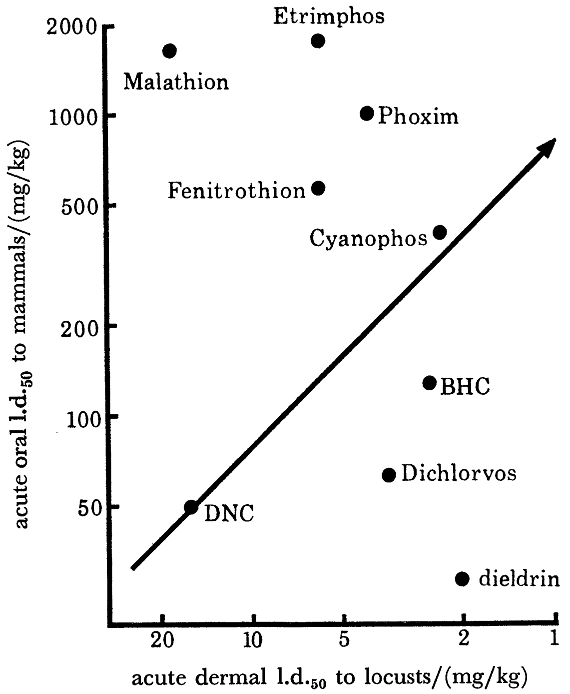

FIGURE 1. Relation between toxicity of some insecticides to locusts and mammals. The arrow shows the direction of increasing relative safety in use.

6. ALTERNATIVES TO ORGANOCHLORINE INSECTICIDES

Alternatives to BHC and dieldrin have always been available and have been used on different scales in different countries: in some, for example Australia, Morocco and South Africa, the use of these organochlorine insecticides is restricted or forbidden. Extensive tests of insecticides against locusts were carried out by the Anti-Locust Research Centre, and during the last few years this work has been extended in an FAO project housed with the DLCOEA designed specifically to study the implications of using alternatives to BHC and dieldrin (MacCuaig 1974). From the many insecticides tested it is possible to select a series of compounds showing a trend towards increased safety in use (figure 1). Of the insecticides shown in the figure, BHC, dieldrin and DNC have already been mentioned. All the other compounds are organophosphorus compounds. Fenitrothion and Malathion are the most used materials for swarm control, the former being generally recommended against the Desert Locust. It is highly effective with kills of a half to one million adults per litre expected from area-dosages of around 400 g ha^{-1}. The advantages of fenitrothion are that the technically pure concentrate is suitable for ultra-low-volume spraying: the precautions required for its safe use are not excessive and the technical material stores satisfactorily. In Australia it is the compound of choice against both nymphs and adults at dosages of about 350 g ha^{-1} and it is stated that it remains effective as a stomach

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

poison for over 10 days after application (Casimir 1976). This treatment may be compared with an application of 20 g ha^{-1} of dieldrin against nymphs of the Desert Locust. Both formulations, i.e. technically pure fenitrothion and Ensodil 20, have about the same contact toxicity to mammals but dieldrin may be stored in the mammal's body, particularly man, unlike fenitrothion which also does not present a long term environmental hazard. However the relative costs of treatment are very different. On current prices 350 g fenitrothion will cost

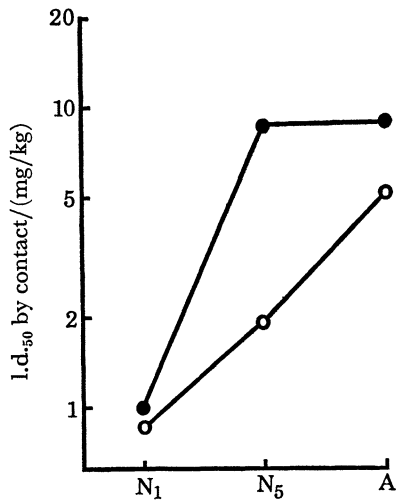

Figure 2. Differences in susceptibility of Desert Locusts of different instars to γBHC (●—●) and dieldrin (○—○) N_1, first instar nymphs; N_5, fifth instar nymphs; A, adults.

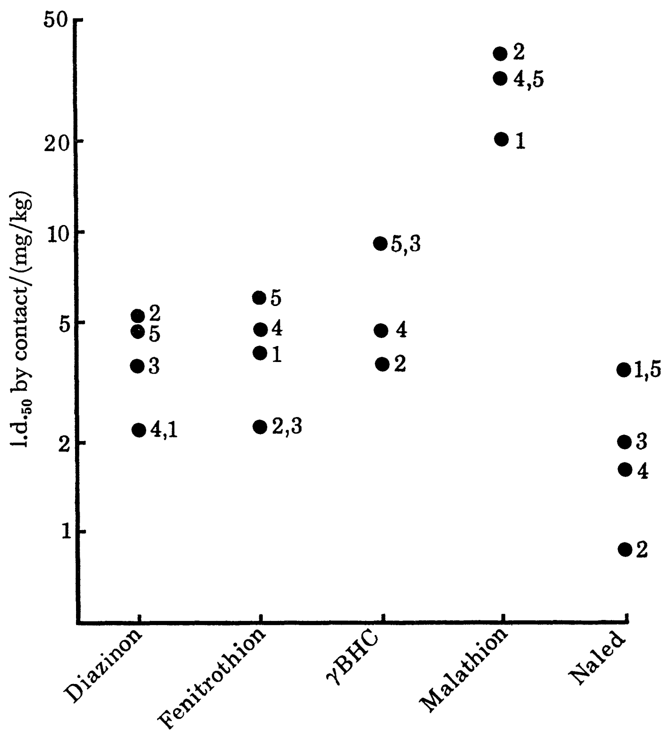

Figure 3. Similarities in susceptibility of a number of insecticides to different species of locust. 1, *Chortoicetes terminifera* (Walker) (Edge & Casimir 1975). 2, *L. migratoria*. 3, *N. septemfasciata* (MacCuaig 1966). 4, *Patanga succincta* (Linnaeus) (Ratanawaraha, Pojananuwongse & Keedkien 1971). 5, *S. gregaria* (MacCuaig 1966).

nearly 11 times as much as 20 g dieldrin. In addition fenitrothion must be applied as a fairly complete cover requiring an estimated 3–5 times as much spraying time (vehicle or aircraft) as dieldrin application. Malathion is safer to use than fenitrothion but because of its lower toxicity to locusts has to be applied in greater quantities. The other insecticides shown in figure 1 all have points of interest: Dichlorvos because it is the fastest acting insecticide and one of the most toxic tested against locusts. It has several disadvantages, one being that it is highly volatile, so much so that when sprays were applied in the laboratory to flying locusts its toxicity decreased appreciably. Field tests appeared to confirm these findings. The remaining insecticides have not yet been used on a large scale in the field. All are physically suitable for spraying undiluted as u.l.v. formulations. Etrimphos was only first tested against locusts in 1976 and no more can be said than that it is promising. Phoxim is a highly toxic insecticide with a very short persistence: of considerable merit when considering it for swarm spraying but making it generally unsuitable for use against nymphs when toxic effects for a few days are desirable. Cyanophos is mentioned because its relatively low toxicity to mammals is combined with a high toxicity to locusts and *Quelea* birds, which make it a possible dual purpose chemical for organizations such as OCLALAV and DLCOEA which carry out control against both locusts and birds.

Detailed laboratory studies have emphasized the variability of insect susceptibility to insecticides. When a series of 53 measurements of the toxicity of DNC were made over a number of years the numerical values of l.d._{50} obtained could be fitted to a normal distribution curve with 95% limits of 9 and 18 mg/kg (MacCuaig 1958). Other experiments showed how the l.d._{50} could change from one instar to another, the changes being different for different insecticides (figure 2). By manipulating the conditions of the experiment the l.d._{50} of dieldrin could be varied by a factor of 14 (MacCuaig 1968). Differences between the toxicity of insecticides to different species of locusts may be large: *L. migratoria* always seems to be more susceptible than *S. gregaria*. However when the commoner insecticides were tested against a number of different locust species by similar techniques applied to the same instar the similarities between species were very striking (figure 3).

Recent studies of possible new insecticides for locust control have included tests to ensure an adequate degree of safety in use. Experiments were carried out to determine the degree of contamination of vegetation following the spraying of known amounts of insecticide. Sheep or goats were then tethered so that they had to feed on vegetation sprayed with ten times the amounts of insecticides estimated to result from locust control operations using particular experimental compounds. The animals were observed for signs of poisoning which were sometimes seen and blood samples were taken for measurement of blood cholinesterase levels which were sometimes lowered. Tested in this way fenitrothion readily met the safety requirement.

As described earlier it is the persistence of the toxic effects of dieldrin after application that makes it so useful in locust control, and new insecticides have also been studied with reference to this property. Vegetation was treated with small known amounts of insecticide formulations and left outside under tropical or semi-tropical conditions. Estimates were made of the residual effectiveness of the insecticide after various time intervals by chemical measurement and bioassay using locusts. One series of tests using first instar nymphs of the Desert Locusts showed how quickly toxicity is lost by many insecticides on exposure to day-time conditions. Thus 1 μg or less of diazinon, etrimphos, fenitrothion, phoxim or propoxur gave 90–100% mortalities when the treated vegetation was offered to the nymphs immediately after application of the insecticides. After the vegetation had been left outside for two days the same amount of fenitrothion gave no mortality, three times as much diazinon, etrimphos or propoxur gave kills of 30% or less, while 30 times as much phoxim did not give a complete mortality. Cyanofenphos, decamethrin, dieldrin, mecarphon and photodieldrin all gave kills of 80% or more under the same conditions with an original application of 1 μg (see table 1).

Table 1. Kills obtained from first instar nymphs of the Desert Locust when individuals offered wheat seedlings treated with known quantities of insecticides

		% kill in 48 h after presenting treated leaf to insect	
insecticide	dose applied to leaf (μg)	leaf given to insect at once	leaf left in open for two days
cyanofenphos	1.0	80	80
decamethrin	0.33	100	—
	1.0	—	100
diazinon	1.0	90	—
	3.3	—	0
dieldrin	0.33	100	—
	1.0	—	90
etrimphos	0.33	100	—
	3.3	—	30
fenitrothion	1.0	90	0
mecarphon	0.33	100	—
	1.0	100	80
photodieldrin	0.33	100	100
phoxim	1.0	100	—
	10	—	55
propoxur	0.33	100	—
	1.0	—	20

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Discussion

R. Le Berre (*Onchocerciasis Control Programme, Ouagadougou, Upper Volta*). I would like to ask Mr MacCuaig if he has experience with:

> decis (decamethrin), one of the latest synthetic pyrethroids, which was efficient against tsetse flies at the very low dosage of 0.16 g per hectare, and lasted for a few months; endosulfan, which we now use against tsetse flies at a dosage of 12 g per hectare; and chlorphoxim, which is much less toxic than phoxim.

R. D. MacCuaig. The only results I have on decamethrin are the laboratory tests quoted in my paper, but I understand from M. Castel that they have tried it on a small scale in the field, and that it is extremely promising, at dosages equivalent to those of dieldrin; it is the most promising material we have at the moment. Endosulfan we have tried and it is not very toxic to locusts; and as far as I know we have not tried chlorphoxim, but Mr Thompson may be able to comment.

A. T. Thompson (*C.O.P.R., London*). We have tested chlorphoxim at C.O.P.R.; its contact toxicity to adult Desert Locusts is about the same as that of phoxim (l.d._{50} = 3.5 and 3.1 μg/g respectively), but both of the compounds were unfortunately considerably less toxic to hoppers.

J. M. Castel (*OCLALAV, Dakar, Senegal*). We do tests in the field, and on insects taken in the field, whose resistance can be quite different from the insects of laboratories. Decis (decamethrin) is certainly a very interesting insecticide for our job; it is about a hundred times more toxic to locusts and grasshoppers than the other insecticides, and its persistence under tropical conditions (cotton fields) is about 12 days. Another important feature is its low toxicity to birds, about 1000 mg/kg for some of the most sensitive species. Fenitrothion, on the other hand, which is recommended for locust control is quite toxic for birds (about 20 mg/kg), for which (unlike mammals) it is extremely cumulative. I have seen birds killed by it in the bush, and in Cape Verde I was told some months ago that birds had been seen dead after fenitrothion spraying, when insectivorous birds eat grasshoppers on the ground.