Strategies, Systems, Value Judgements and Dieldrin in Control of Locust Hoppers [and Discussion]

D. L. Gunn, M. R. Tucker, O. M. S. Abdallahi, R. Le Berre, J. M. Castel, J. Roy and H. D. Brown

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SYSTEMS AND MANAGEMENT

Strategies, systems, value judgements and dieldrin in control of locust hoppers

By D. L. Gunn
Taylors Hill, Chilham, Canterbury, Kent CT4 8BZ, U.K.

The physiology and field biology of locusts have been extensively studied, and ecological control of Red Locusts has been investigated by field experiment. No fruitful or even promising non-insecticidal method of control has emerged.

An effective and economical system requires an insecticide that is: (i) effective at very small area dosages, as a stomach poison placed on the natural vegetation can be, if it is also cumulative; (ii) persistent enough in sunshine and rain to retain effectiveness over the locust's non-feeding periods; (iii) capable of being well distributed by well-tried methods; and (iv) not dangerous to users or consumers and posing a minimal overall risk.

Only one insecticide, dieldrin, satisfies all these requirements. Dieldrin is not in the small class of insecticides that are dangerous to man by skin absorption (such as parathion, arsenicals, DNC) and, at the area dosages needed for locust control, is not dangerous to stock. The Sayer exhaust sprayer in a Land Rover, with work rates of the order of square kilometres per hour is excellent for many situations; aircraft spraying at the rate of square kilometres per minute is quicker and less subject to difficulties of terrain, but requires trained and appropriately directed aircrew. Apart from checking, aircraft methods require no party on the ground to find, assess and control locust hoppers.

Several ideas about dieldrin are found to be based on insufficient evidence and are probably not true: for example that dieldrin in the atmosphere at a few parts in a million million (10^{12}) becomes concentrated in a food web and harmful to man, or that dieldrin is carcinogenic in man. It is noteworthy, however, that one species of antelope in South Africa is exceptionally susceptible to dieldrin poisoning, though harm occurs at area dosages considerably greater than are required in the method of aircraft spraying of Courshee & McDonald (1963). To attack tsetse flies, emissions two orders of magnitude greater have been used.

Care must be taken with any insecticide, but the risks of using dieldrin as properly used in locust hopper control have been exaggerated by propaganda. If harm is to be expected, then a quantitative comparison of that with the undoubted benefits of locust control is required to enable one to make a value judgement.

1. Introduction

The ideal method of pest control requires no more than to be started off and then to be self operating. A few examples of biological control are like that, based on introduction of a crop from a far country accidentally carrying one of its pests but without that pest's parasites. The later introduction of the parasites has occasionally produced once-for-all control.

This prescription is not applicable to locusts, which plague their own home range; although they have parasites and predators, these do not prevent the vast population increases that occur in favourable weather. Attempts to use pathogenic fungi and bacteria have failed: the fungi occur anyway when the weather suits them but do not prosper at other times.

(*a*) *Ecological control*

Type B locusts, with few rather well defined outbreak areas, might be susceptible to other forms of ecological control (Gunn 1952*a*, *b*, 1958), long suggested (by, e.g. Uvarov 1928, 1977) but rarely tried. Experiments on Red Locust outbreak areas were carried out up to 1958 (Robertson 1958*b*; Gunn 1958, 1960*a*). The hoppers of this species develop in flood plains when they are not flooded; these plains are free from trees; the grass in the breeding zones is a mosaic of tall and short species; and the eggs are characteristically laid in soil where the grass has been burnt off.

To drain the flood plains was not possible, for there are no outlets leading to the sea, but extra flooding was tried by damming the outflow from the Iku-Katisunga plain in the Rukwa valley, and a detailed feasibility study was made of keeping Lake Mweru wa Ntipa from drying by partly diverting the Kalungwishi river (Gunn 1960*a*). The quality of the alkaline clay soil in the plains may explain the absence of trees, but *Tamarindus indica*, *Melia azederach* and certain species of *Eucalyptus* survived and grew for a time, at least; destroying the mosaic by the use of herds of cattle to eat off and trample the grass was tried but would be very expensive, for the grass clearance programme did not produce marketable beasts; fire prevention was successful in concentrating the egg-laying into the fire-breaks, but could not be maintained for long, diametrically against the needs and practices of the local villagers.

In any case, a few years later (from 1962) an enormous area of Africa, including much of the Red Locust invasion area, went through a succession of wet years and the normal outbreak areas – including the tree-planting trials – were continuously flooded and quite unproductive of locusts. At the same time, however, other areas probably normally too dry for large-scale locust breeding became active as outbreak areas, producing some emigrant swarms, though up to 1977 no plague. This weather switch would have frustrated any structural changes made in the classical outbreak areas. Ecological change seemed to be too slow and inflexible for success.

(*b*) *Physical methods*

The old mechanical methods of driving hoppers into trenches, beating them, collecting with machines and so on have all been failures in themselves and in any case quite unsuitable for the magnitude of the task and never used professionally; but they are still quoted. Flame throwers have been tried but spraying the paraffin as an insecticide – and a poor one it is – killed more locusts than using it to make a flame, when most of the hoppers escaped.

(*c*) *Insecticide methods*

In fact, even for type B locusts, there is no promise of control by ecological methods and no known effective method of controlling hoppers without using insecticide.

From 1880 to the 1950s, locust hoppers of several species were attacked by means of moistened poisoned bait, usually arsenical, based on wheat bran or some material of similar consistency. This had the disadvantage that the bait was not taken after it had dried up, which it did within a few hours in hot sun. With the newer insecticides, especially BHC (HCH) as fine powder, the bait could be used without water, this was just as effective when fresh and, with certain insecticides, remained effective for a long time (Gunn 1952*a*).

For very large areas, as required for the Desert Locust, there was above all the disadvantage of the very large tonnages of bait needed wherever outbreaks might occur; in addition, large numbers of labourers were required to throw the bait in the way of the hopper bands. There is also a problem of scouting, particularly severe for the Desert Locust, which is dealt with by R. J. V. Joyce (this symposium).

Since 1947, when the new synthetic organic insecticides began to be available and arsenic compounds could be abandoned, new conceptions of attack were sought, the requirements to be satisfied being as follows.

It should be understood that the insecticide to choose and the method of distributing it have to be considered as an integrated whole. The insecticide must be:

(*a*) a stomach poison, for hoppers are often so shielded by one another and by vegetation that contact poisons would fail to reach many; and with sufficient persistence stomach insecticides can be effective at much smaller area dosages;

(*b*) persistent enough in sunshine to retain effectiveness nearly fully over the non-feeding days around hopper moulting (Ellis 1951, Davey 1954, Chapman 1959) which wet bait and volatile or unstable insecticides all fail to do;

(*c*) cumulative or not easily excreted or detoxicated by locusts, so that very small transport-saving area dosages are effective when consumed over several days;

(*d*) not dangerous to users or consumers, whether human or domestic or wild animals; and

(*e*) cheap in use, as insecticides go.

The following paper describes how and how far these requirements have been satisfied in developing strategies and systems and how value judgements must in the last analysis be applied.

2. Methods

(*a*) *Vegetation baiting*

Much of the cost of controlling hoppers of the Desert Locust was the cost of buying, storing (perhaps for years) and especially transporting many tonnes of bran for bait. In 1953, Vernon Joyce proposed reviving (Gunn 1952*a*) what he called 'vegetation baiting', by using the standing vegetation as the bait and applying insecticide to it. This could be done with new insecticides that do not harm the vegetation. At that time, a machine was being developed for spraying contact insecticides and dieldrin had just become available. This combination was set on to trials of vegetation baiting. H. J. Sayer (1959) in East Africa developed the idea there while Courshee (1959) discussed the theory fully, based on field trials in the Sudan with a very cheap spraying machine called the Innominate or Weardling (incorporating the surname Ward and the initials NIAE and DLG).

(*b*) *Exhaust-nozzle spraying*

Sayer used an even cheaper system which was also more suitable than the Weardling for terrain not entirely smooth. He mounted in the exhaust pipe of a vehicle (Land Rover) a specially designed fitting to make the spray (Sayer 1959, Rainey 1960). Fine spray of stomach poison was then emitted downwind while driving the vehicle square across the wind. This made a wide band of vegetation toxic to locusts when they ate it. Another such band would then be laid upwind, parallel with the first, at a distance determined by the terrain and the distance likely to be marched by the Desert Locust hoppers. Possible effects on local domestic animals were tested by field trials (§ 4).

At the small area dosages being used (§ 4) a hopper would not necessarily acquire a lethal dose from a single meal. Some insecticides are not persistent in sunshine, being too volatile, e.g. DNC, which is also detoxicated quite quickly by locusts (Kikal & Smith 1959), so that a sub-lethal dose contributes little to the subsequent mortality at further dosing several days later (MacCuaig & Sawyer 1957). On the other hand, dieldrin is lost only slowly both from the vegetation and, by detoxification, from the insect (Cohen & Smith 1961), so a lethal dose can be built up as several non-lethal doses on successive days.

So in dieldrin we already satisfy several requirements, a stomach poison for locusts, persistent, and cumulative in the locust. It works well in the Sayer exhaust sprayer. Since this can only go where a Land Rover can go, aircraft attack may often be necessary, and that has other advantages too.

(*c*) *Aircraft spraying*

A technique basically similar to Sayer's was reached independently by Mallamaire & Roy (1958) against Desert Locusts in West Africa and by Lloyd & Yule (1959) against Red Locusts in an outbreak area. In both cases and independently, dieldrin was the insecticide chosen. The strips of this insecticide were laid by an aircraft instead of a ground vehicle and cross strips were also put down, making a lattice. The details of flying height, spray formation and formulation of insecticide are no longer fully applicable. The idea of using such a lattice for marching hoppers seems to have been first put forward by Du Plessis (1949).

The striking facts with both species were that the mortalities achieved were exceptionally high, sometimes complete, and that the costs were lower than those of other methods (Sayer 1959, Lloyd 1959, Yule 1960). Further, hundreds of square kilometers could be treated quickly and economically. Bennett & Symmons (1972) reviewed the effectiveness of such methods against the Desert Locust.

Nearly complete mortalities are indeed necessary. Hemming *et al.* (this symposium) report 200 times as the potential increase in the Desert Locust at a single breeding, with an actual increase of 16 times up to fourth instar in a particular case. In favourable breeding years, a Red Locust may lay 200 eggs (Robertson 1954, 1958*a*), and even with the usual large mortality in early life there is slight evidence that a population past the earliest hopper stages may be as large as fifty times the parental population (Gunn 1960*a*, p. 97). If the following generation is not to start off with a larger parental population, then all but 6% or as little as 2% must die or be destroyed before breeding. A mortality of 98% or even 94% is more than almost any other control problem requires and is seldom achieved artificially.

A further stage in aircraft technique for the Desert Locust was reached by Courshee & McDonald (1963). Assuming the use of a cumulative and persistent stomach poison, they calculated that it need not be applied in denser strips through which the hoppers must march; a uniform dosage using the same total amount spread over the whole area would be just as good against marching hoppers, would also control non-marching individuals and would pose less risk to grazing vertebrates.

To achieve a wide swath, with impaction on vegetation and little deposition on the ground, droplets of diameter 100 to 120 μm (even up to 150 μm) were used (for drop formation, see Gunn, this symposium, § 10). The aircraft was flown square across wind at about 25–35 m above ground. At 100 m high, no spray was detected on the targets, so Courshee & McDonald recommended that flying height never exceed 50 m. By this technique, swaths up to 1.6 km have been used, with no need for cross latticing.

The results obtained with dieldrin in practical spray operations at deposits of only about

1 ppm on the vegetation require emitted dosages in the Desert Locust hopper areas of no more than 12 g ha^{-1}. Thus 50 km^2 was treated per hour in the sparse vegetation areas of the Indo-Pakistan border (Courshee & McDonald 1963). They recommended that a working rate several times faster could be achieved with larger aircraft, depending on the distance from the landing field. In moderately luxurious vegetation somewhat higher dosages would be required; Roy is quoted as proposing 24 g ha^{-1} emission. Courshee & McDonald used the technique on 230 km^2 infested with bands of fourth and fifth instar hoppers, the most difficult stages to kill, with well assessed and strikingly complete success. A later publication by Courshee (1965) gives a comprehensive theoretical analysis of the information available. He calculates that, with a longer time than 2–3 days available for the hoppers to feed, still smaller dosage rates would suffice (cf. Joyce, this symposium). In this second paper, Courshee reverts to the original conception of spraying barriers instead of depositing insecticide over the whole area.

3. RED LOCUSTS

In the Red Locust outbreak areas, the vegetation consists of a mosaic of species of grass; the hoppers roost in the tall grass and descend to feed, mainly on the short grass (Chapman 1959). The emitted dosage of dieldrin to be used in this case remains to be found by systematic trials. Presumably the species is about as susceptible as the Desert Locust and the spray deposit should be 1–2 parts/10^6 on those parts of the grass that are eaten by the hoppers.

For a long time, the need has been to use aircraft for control without the aid of anyone on the ground. (Independent checks by a ground party are, however, necessary, as will now be seen.) In order to assess the significance of what can be seen from an aircraft, the structures of hopper populations have been thoroughly studied (Scheepers, Eyssell & Gunn 1958; Yule & Lloyd 1959; Dean 1967; Dean & Crosse-Upcott 1968). Thus it has been shown that more than half of the population, even when large enough to be dangerous, may be scattered and not in bands at all. Searching for bands by looking from aircraft at best never discovers more than half of the bands and sometimes less than a quarter of them. That is to say, direct attack on those bands that are seen at a single inspection might at best kill a quarter of the hoppers present but is more likely to kill less of the total there. Such an operation would have to be repeated several times to produce a gradually increasing but still deficient mortality, so that the idea of direct attack on bands is wrong and wasteful. Direct air attack on individual hopper bands was also used against Desert Locusts in East Africa in 1954–5, but was later abandoned when the performance of dieldrin spray lines had been established.

The proper use of available skills is to regard visible bands as indicating an area to be sprayed, including spaces between neighbouring bands (see also Joyce, this symposium). The technique of Courshee & McDonald is clearly the appropriate one, aided, for example, by Yule's (1960) method of marking, simply by dropping from 25–30 m partly opened rolls of toilet paper, which rapidly unroll in descending and remain conspicuous from the air as they lie on the ground. Suitable electronic track-guidance systems are also now well tested, and also important to help avoid over-dosing.

To kill only a quarter and perhaps no more than one tenth of the hoppers by direct attack on bands is sheer waste of resources, when a kill of over 90% is required and can be achieved in a single operation. Nevertheless, even in a fairly recent memorandum on theory and planning of preventive Red Locust control, when few bands are discovered from the air the recommendation made was still to spray individual bands (Malujlo 1973). If that policy has been followed in recent years, no further explanation is required for the migrating swarms that have, for example, been reported leaving the Wembere area of Tanzania.

Behind the airmen and field teams in general, there has to be an efficient headquarters system of supply and control, led by somebody who thoroughly understands the matter, connected by radio telephone, and with a backing organization to supply the money. Headquarters must be responsible for the disposition of forces between areas and for ensuring that the work is done properly. These points, the organization and the quantities of supplies needed and their disposition and use in 1957–8 in West Africa were also described by Mallamaire & Roy (1958).

For the Red Locust, planning has so far been aided by a long-period forecasting system that has still to be fully tested (Gunn 1955, 1956, 1960*b*; Gunn & Symmons 1959; Symmons 1959).

4. SAFETY

It is now well understood that although many materials in daily use – some of them in the ordinary kitchen – are poisonous, that does not debar them. With suitable precautions we do use bleaching agents, antiseptics and so forth.

Insecticides are chosen because they are toxic to certain insects; their toxicity to non-target insects, to domestic animals and wild animals and to man may be similar or may be quite different.

Among the least selective and most toxic insecticides are DNC (formerly used for quick penetration and kill but now largely abandoned), arsenical compounds (no longer used much since the synthetic organics became available and, like DNC, also damaging to plants) and parathion (a phosphorus compound, quite the most toxic to both locusts and rats). All of these have killed users and are liable to cause trouble by skin penetration; parathion has been quickly fatal, but no deaths from any insecticide have occurred among users in Britain since 1952. The most toxic materials in very common use against locusts are dieldrin and γBHC; they are both best used as stomach poisons, though at larger doses they also act as contact poisons. They have never caused a single death amongst users or human food consumers (Gunn 1975*a*, *b*). Drinking concentrated insecticide from a bottle of it is naturally not at all safe, for even the solvents may be poisonous at large doses.

From the early days of synthetic organic insecticides for locust control, toxic hazards have been closely watched, not only by the locust control authorities and the research workers that they supported in Britain and in the field, but also by the Medical Research Council Toxicology Laboratory and by the manufacturers. Thus before any general introduction of exhaust spraying with dieldrin (and some years before Rachel Carson's 'Silent Spring' (1962) appeared), field trials were done on sheep and goats in north Kenya; there was no analysis of chemical deposits but the dose rates in the animal trials, using the Sayer system, were two to six times the normal for hopper control. The animals were tethered in the sprayed area for one week. One goat died two days after the end of the week from what was then considered, after post-mortem examination, to be pneumonia but may indeed have been dieldrin poisoning. This goat had been tethered closest to the spraying machine, where the deposit was likely to be heaviest, and in any case that grazing had received six superimposed lines of spraying. Such animals are not normally tethered but move fairly quickly, feeding intermittently (Ashall & Hemming 1958; Joyce *et al.* 1962).

The sprayed area remains toxic to feeding locusts for weeks, the duration depending on the initial amount and the conditions of sunshine and temperature; the residue probably declines exponentially. But it does not remain as dieldrin.

(*a*) *Photodieldrin*

Roburn (1963) showed that dieldrin changes in ultraviolet radiation to an isomer, photodieldrin. In the winter sunshine of the high sheep areas of South Africa, 65% isomerization may occur in 10 days (Wiese, Basson & Van der Merwe 1970). Photodieldrin is more toxic to locusts than the original dieldrin (MacCuaig 1974). It is also more *acutely* toxic to most mammals tested – thus a single just-lethal dose of photodieldrin is smaller than a single just-lethal dose of dieldrin to rats, mice and guinea pigs – but not to dogs. Pigeons are more susceptible to photodieldrin, but domestic fowls are not (Brown, Robinson & Richardson 1967). On the other hand, photodieldrin is eliminated more quickly than dieldrin, probably as the keto-metabolite (Brown, Robinson & Richardson 1967; Baldwin & Robinson 1969). The *chronic* toxicity of photodieldrin is therefore correspondingly less. Of course, if the daily dose is larger than the amount got rid of daily, death may result (Wiese *et al.* 1973); but short of such large doses – which man would encounter only in suicide, sheer carelessness or very rare accident – photodieldrin is indeed safer than dieldrin itself.

Laboratory feeding tests on repeated doses of dieldrin, covering weeks or more, are not comparable with field trials, not only because of isomerization in the field but also because some of the insecticide evaporates and growth of vegetation dilutes the remainder.

(*b*) *Safety testing*

There are many papers on the biochemical background and there is a valuable review by Tennekes & Wright (1978). There are substantial indications that different species of mammals react differently. Mice are particularly prone to liver tumours, not only spontaneously but also when treated with chemicals in common use, such as phenobarbitone as well as dieldrin, which may not be the direct causes but may activate causal viruses which are apparently peculiarly common in mice. Demographic evidence has been examined and has given no support to the idea that these are carcinogenic in man; for example effects of phenobarbitone have been investigated on 10000 epileptics, who showed no carcinogenic effect.

A series of investigations of vegetation baiting to control grass-feeding termites in South Africa has extended our information on effects of dieldrin at dosages substantially higher than are needed against locusts. Dieldrin came into question in the food of crowned guinea-fowl because it is sprayed against these termites at an emission rate of 87 g ha^{-1}, giving a residue at first of 15 parts/10^6 on short grazed vegetation. Laboratory feeding trials revealed no cause for alarm (Wiese *et al.* 1969). On the vegetation photodieldrin lasted $2\frac{1}{2}$ times as long as dieldrin; but within oxen and sheep, the half-life of photodieldrin was much shorter than that of dieldrin. Residues per unit of vegetation declined as the grass grew. No harm was done to stock, though dieldrin was naturally found in the milk of the ewes.

In the same area, however, certain antelopes seemed to be particularly sensitive, so young blesbuck (*Damaliscus dorcas phillipsi*) were selected for test. The penned buck were fed with a range of concentrations of dieldrin which gave no mortality at 5 and 15 parts/10^6 up to 90 days, but 25 parts/10^6 caused some deaths with characteristic symptoms in 24 or fewer days. The normal termite-control dosage was 87 g ha^{-1} emitted and initially 15–20 parts/10^6 on the grass; but in a blesbuck experiment in the field the spray was accidentally emitted at 160 g ha^{-1} and the initial deposit was 28 parts/10^6 of dieldrin and no photodieldrin; after 14 days the dieldrin was reduced to 5 parts/10^6 and the photodieldrin had reached 16 parts/10^6. With this large emitted dosage, all the blesbuck died by the 19th day, the mortality being demonstrably due to photodieldrin (Wiese *et al.* 1973). During these field trials, two sheep present in the same area and with the same exposure showed no ill effects and lambed normally in the following spring.

(*c*) *Safety through dosage control*

Clearly, there may be other species of wild life, especially in Africa, as susceptible to photodieldrin as blesbuck, so care must be taken to avoid spraying in such a way that residues as large as these remain available for grazing, a requirement satisfied by the proper application of the method of Courshee & McDonald (1963). There is no evidence that a deposit of about 1–2 parts/10^6 put down by that method is anything but safe and indeed the margin of safety is considerable. That margin would quickly disappear with low-level attack on separate bands, especially if repeated attacks were made.

The emission rates recommended for locust control are very much less than are used for controlling tsetse fly, using dieldrin as a contact poison and not a stomach poison. Coutts & Spielburger (1977) and Spielberger, Na'isa & Abdurrahim (1977) quote an aircraft emission rate of 1500 g ha^{-1} in north Nigeria and other rates not so great but far larger than any used for vegetation baiting. Such figures put the emission rates for locust control into perspective.

So far, only properly ordered situations have been dealt with, but accidents sometimes happen. An aircraft engine may fail, necessitating dumping the whole load of dieldrin quickly; overdosing may result from flying too low, from spraying along the wind instead of across it, and from inadvertently or mistakenly spraying the same area repeatedly (Baron 1972, pp. 213–4), instead of leaving time for the insecticide to act. Dieldrin should never be used as a contact spray against locusts, because that requires much larger dosages, and it should never be used for drenching for population assessment, so need never be sprayed along the wind. If a grossly excessive dose is deposited, it should be treated as an emergency, with cattle and game kept out, until clearing procedures have become effective.

There remains no indication that a deposit of 1–2 parts/10^6 of dieldrin on vegetation put down by the method of Courshee & McDonald (1963) is in any way unsafe; it is certainly the method to choose for controlling locust hoppers.

5. PROPAGANDA

Any use of dieldrin has been criticized as adding to the dieldrin in the world, so this must now be examined.

(*a*) '*Silent Spring*'

Propaganda about pesticides began to be popularly effective with Rachel Carson's 'Silent Spring' (1962), which had two important aspects. It usefully induced many people to concern themselves for the first time about the environment and in particular what chemicals (not only pesticides) might do to it, some people being more concerned about risks to human beings and others about risks to wild life; the emotional attitude so introduced is, of course, essential to any drive to get things changed. Second, however, it inserted that emotional attitude into science in such a way that it caused a reduction of quality, a lack of objectivity especially in relation to politics (Gunn 1972, 1975*b*).

In her quest for popular support, Miss Carson made several serious mistakes. First, she was uninfluenced by the ancient pharmaceutical truth, expressed in a free translation of the words of Paracelsus of nearly 500 years ago: 'Everything is poisonous, yet nothing is poisonous', depending of course on the size of the dose (Barnes 1969, Jukes 1971). Some substances at small dosage are harmless or even necessary to life, though lethal at large dosage. The conception that a poison at any dose, however large, is still a poison at every dose, however small, is now accepted in the U.S.A., in regard to chemicals initiating cancer, by the Delaney Clause of the Food Additives Amendment (Jukes 1971, 1976). Referring specially to carcinogens, this is based on the idea that if a particular substance administered to any species of animal seems to cause cancer, then that substance must not be used in such a way that it might enter human food in any amount, however small. Even when there is not the slightest evidence or even indication that such a substance causes cancer in human beings, if it does so in mice, then it is forbidden (but see Tennekes & Wright 1978).

Second, Miss Carson propagated the 'tomato heresy' (Gunn 1972). Early in the century, tomatoes were uncommon and were believed by many to cause cancer; since then, nobody has proved either that they do or that they do not but we now eat large numbers of them. Once it has been alleged that DDT causes cancer and once people believe this, it is like the tomatoes. Nobody can deny the carcenogenicity of the insecticide, although nobody has demonstrated that DDT or dieldrin in the minute doses to which we are all subject do or do not cause cancer or other ailments. It is impossible to prove such a negative proposition in general, but the evidence is against carcenogenicity, as far as it goes (Gunn 1972, Jukes 1974, Barnes 1973, 1976). In any case, the doses given to mice are very large, so that any carcenogenicity may be due to that, simply because they overwhelm mechanisms that are quite adequate for complete protection with normal doses (Gehring 1977).

Third, Miss Carson did not, and many of those who are specially interested in wild life do not, take fully into account the positive case for the use of such insecticides, find the balance of advantage including the values of human health and happiness and come to a value judgement (Barnes 1966, Wright 1976, Jukes 1974, Gunn & Stevens 1976, Gunn 1977, Perring & Mellanby 1977). It has been said that 'the flowers, birds and bees' are apt to hide from sight the 'sick and hungry men, women and children' (Bruce-Chwatt 1971).

(*b*) *Value judgements*

Unanimity cannot be reached in value judgements, for these depend fundamentally on what one wants. Once the basic needs of food, shelter and a mate are secured, human wants may concentrate on more or better of these or may turn to quite different objectives, such as the arts, competitive games or wild life. Whichever objective provides the emotional attitude necessary to lead to action, that attitude is liable to neglect any consideration of balance or relative values. Surely, however, we should all judge the relative values in this matter, which cannot be put into the same units of account: hypothetical hazards to man or beast due to the continued use of a particular pesticide, on the one hand, should be set against, on the other hand, the undoubted losses of health and even life to very many human beings, which would result from abandoning that pesticide. Surely the unsatisfied basic needs of millions of people should weigh heavily and should not be put aside by enthusiasm for objectives of more prosperous people. Such a weighing up, a value judgement, is entirely personal, difficult to make conscientiously and not readily defensible to other people with different wants, so differences persist.

(*c*) *Accumulation*

The public would not so readily accept the idea that a few parts of DDT or dieldrin in a million million parts could do harm, were it not that the idea of accumulation in food chains was put forward and has since been widely quoted as revealed and universal truth in various official enquiries. Some examples given are indeed untrue (Gunn 1972, Moriarty 1972*a*, 1972*b*); thus it was stated that after the application of DDT to Clear Lake in 1949 to control gnats, 5 parts/10^6 of DDT was found in the plankton (Carson 1962); this is untrue, for the amount of plankton caught was too small for analysis by the methods then available and indeed the alleged author of the analysis has denied it. Nevertheless, true examples do exist. The fact is that although some predators have larger body burdens of DDT, for example, than their prey, others have smaller concentrations. That depends on the relative effectiveness of the absorption, detoxication and excretion systems of the two species (Moriarty 1972*a*, 1972*b*). Some species of predators are more effective in these matters than their prey, so that far from biological accumulation occurring, there is then biological dissipation or destruction. Biological accumulation along a food chain should never be assumed without direct evidence of the case in question.

If we were to worry about the minute traces of DDT and other compounds very widely detected and even measured in vanishingly small concentrations, we would have scores of poisons to worry about. Indeed, animal species could hardly have survived without suitable and effective systems of defence against foreign compounds; these systems commonly cope with small quantities of many poisons – even entirely novel ones – without recognizable effect.

(*d*) *Give a dog a bad name*

Much of the emotional attitude against pesticides is generated or at least sustained by false, dubious or exaggerated reports (Mellanby 1972*a*), but it exercises powerful political pressure especially in the U.S.A.

An example of jumping to conclusions, by no means unique, occurred on 17 September 1973, when the London *Times* reported tens of thousands of birds dying in the Coto Doñana Reserve in Spain, reportedly caused by 'a highly poisonous pesticide', a 'chlorate' pesticide used 'to fight mosquitoes'. In the *Times* for 9 October 1973, Mr Guy Mountfort representing the World Wildlife Fund reported that the deaths were, on the contrary, caused by 'Type C' botulism. But the truth may never catch up with the first report and even today one may be told of the devastating effect of pesticides in Coto Doñana.

(*e*) *Falcons*

An example of a dubious case is the widespread belief that DDT has been responsible for the decline and eventual elimination of the peregrine falcon from the southern parts of England. This is based on measurements of eggshell weight (for thickness) which indicated a sharp reduction during 1946 and 1947, followed by stability at the reduced thickness from 1948 (Ratcliffe 1967). The explanation of this reduction is unknown, but according to Ratcliffe it coincided with the start of widespread use of DDT, though it is in fact doubtful if DDT was much used until a year or two later, after thickness had become more constantly thinner (Gunn 1972). The thin eggshells were held to be responsible for many egg breakages – which were in fact rare until 1950 and only then became commoner – causing a reduction in hatching. With some adjustment of dates, a plausible reason for a declining population of peregrine falcons could be put forward. As it happens, however, over the whole of that period and up to 1955, the peregrine falcon was increasing in numbers and became reduced only in 1956. There are many reasons for animal populations declining from time to time, the most rigorous being weather; it seems hardly reasonable in this case to attribute the decline of the peregrine falcon in southern England to the effects of the use of DDT on eggshell thickness. Nevertheless that is being put forward as a basis of policy for the whole world.

In the U.S.A. the same species – perhaps a variety and commonly called the duckhawk – has declined in the eastern states and its decline has been attributed to DDT, largely on the basis of the British evidence. Since that evidence itself shows that thinning of eggshells is insufficient to explain the decline of the species, the mass of evidence about eggshells – still being accumulated – is of little relevance especially when factors other than DDT in the food have the same effect. The truth is that birds of prey have been declining in the populous agricultural areas of western Europe since at least the beginning of the century (Ferguson-Lees 1963), before any synthetic organic pesticides came into use. In mountainous areas and in reserves in Europe and the U.S.A. there has in most cases been no such decline and in some cases an increase. When that is so, the species concerned are not liable to be exterminated, an event that we ought to prevent.

(*f*) *Public enquiries and decisions*

In the U.S.A., the properties of DDT and the propriety of using it have been repeatedly investigated by high-level committees. The Administrator of the Environmental Protection Agency appointed an examiner to hear evidence from all concerned about the effects of DDT. In April 1972 the examiner reported comprehensively, having found that 'any adverse effect on beneficial animals from the use of DDT under the registrations involved is not unreasonable on balance with its benefits' (Sweeney 1972). In June 1972, however, the Administrator, W. D. Ruckelshaus, virtually ignored the examiner's recommendations and forbade nearly all uses of DDT in the U.S.A. (Gunn 1975*b*). In so doing, he made statements contrary to the considered findings of the examiner and at variance with the weight of evidence taken at the hearing (Ruckelshaus 1972).

Consequently the case was taken to the U.S. Court of Appeals which delivered what is by scientific standards a most extraordinary judgement (U.S. Court of Appeals 1973). The Court decided that it need not weigh the evidence for and against, but had only to decide if there was 'substantial evidence' against the use of DDT, apparently irrespective of countervailing information that might completely undermine the evidence produced. The administrator, the court decided, could equally well have taken the opposite course based on other evidence presented and an appeal against such an opposite decision would have been equally unsuccessful.

Later, in 1974, the administrator banned both the use and also the manufacture of aldrin and dieldrin in the U.S.A. *without even hearing evidence* available to offset that given on ill effects of dieldrin. British 'judges have regularly asserted the importance' of a requirement of natural justice, namely to 'give both sides an equal hearing' (Anon. 1978). In view of the Appeal Court pronouncement in the DDT case, any appeal in this case was felt to be a waste of time. The administrator's views and the regulations that arise from them do not appear to be soundly based. Since they do not reflect the views of those scientists best qualified to form a balanced and objective judgement, they appear to provide an unsound basis for world policy on these pesticides, especially as they do not take into account the welfare of hundreds of millions of people outside the U.S.A.

(*g*) *Pressures against best choices*

At the tenth General Assembly of the International Union for the Conservation of Nature, held in India in 1969, a Committee on the Ecological Effects of Chemical Controls required evidence of damage of economic significance before allowing attack on a pest (IUCN 1970*a*); on that basis, there would often be no hope of nipping a locust outbreak in the bud. Other incursions into pest control included the outline of a research programme for applied workers. The committee also questioned whether technologically advanced countries should be *allowed* (*sic*) to produce organochlorines for export to other countries that needed them. Finally the General Assembly recommended (Resolution 27) that the use of DDT be stopped by all states and international agencies 'except for emergency human health purposes' (IUCN 1970*a*, *b*). The activities of this organization may indeed bear upon health and survival in less developed countries, in so far as the recommendation is heeded.

Even had the proposals been agreed to without the inserted clause on emergencies, it is unlikely that the World Health Organization and the Food and Agriculture Organization of the United Nations would have accepted and acted upon it, because of the unique value of DDT. Thus DDT was responsible for saving an estimated 15 million people from premature death from malaria alone between 1955 and 1965 (Bruce-Chwatt 1971). In addition, DDT diminished death or illness from filariasis, dengue, onchocerciasis (leading to river blindness), trypanosomiasis (transmitted by tsetse in Africa and by bugs in South America), typhus and plague (Wright 1976). No fully suitable substitute has been found for DDT as a persistent residual insecticide for spraying inside houses, in spite of tests of approaching 2000 candidate substances.

A series of high-level official committees in Britain have pronounced on these matters, from the Zuckerman Committees (1951, 1953, 1955) onwards (Gunn 1975*b*), reaching conclusions not very different from Sweeney on DDT (1972) and O'Brien (1972, 1973) on dieldrin; their recommendations have, however, been more highly regarded administratively.

The Wilson Committee (1969) concluded that 'there is no close correlation between the declines in populations in predatory birds, particularly in the peregrine falcon and the sparrowhawk, and the use of DDT. Therefore DDT does not appear to have been the principal cause'. Nevertheless DDT has been blamed for declines in population of predatory birds in the U.S.A., possibly with inadequate justification, and this blame has been the main reason for banning DDT there. The necessity of using persistent insecticides at feasible prices in the tropics have generally not entered the argument there, but in Britain it is held that 'in tropical countries where food production is vital and there is a high incidence of mortality from insect-borne disease, the hazards to wildlife and the presence of minute residues in human fat may rightly be regarded as relatively unimportant' (Wilson 1969, p. 64).

One effect of this attitude about DDT and dieldrin in the U.S.A. is that countries which may want to export meat to the U.S.A. cannot use these persistent insecticides for controlling serious pests on the beasts or in grazing areas, because of the residues that remain in the meat and may exceed levels acceptable in the U.S.A. The producers may thus have to bear extra expense and loss.

The matter has now gone further, however. It is reported that 'pesticides that have not been approved for use within the United States will no longer qualify for assistance from the U.S. Agency for International Development' (i.e. the AID programme) (Anon. 1977*a*). Such pesticides include DDT and dieldrin and the implication seems to be that AID funds will not be provided for the use of dieldrin to control locust hoppers†. Since a jointly supported FAO/SIDA Locust Project (Swedish International Development Authority) had, by October 1976, screened some fifty of the more promising insecticides as replacements for dieldrin without being able to select anything fully suitable (*see* MacCuaig, this symposium) (Anon. 1976), the continued use of dieldrin for hopper control was recommended by the FAO Locust Control and Emergency Operations Group (Anon. 1977*b*). It has since been pointed out by a representative of less developed countries that in choosing an insecticide, views other than those held in donor countries should be considered, especially the views of those representing millions of people in the less developed countries, whose choice was between lack of food and even starving to death against some dubious risks of slight poisoning (Abdallahi *et al*., this symposium).

(*h*) *Final choices*

The campaign to stop use of DDT and dieldrin everywhere in the world is based on worries about effects of minute quantities and about accumulation in food chains; that is why one country claims an interest in the choice of insecticides by other countries. In view of the basis for and the nature of the opposition to using the most safe and effective insecticides, the conclusion to be drawn is that each country should examine the scientific evidence for itself, in relation to its needs, and decide what pesticides it should use and by what methods, irrespective of mass propaganda elsewhere. The attitude of a country exposed to large scale malaria or locust damage can reasonably differ from that of a country not so exposed.

That is where a value judgement becomes necessary (Gunn & Stevens 1976, Gunn 1977). There is no common criterion for comparing thousands of deaths of people from malaria or starvation with some hypothetical risk to stock or to wild life, so each person has to decide their values for himself. On a world scale, the choice is between the health and happiness of a thousand million human beings – many of them chronically under-fed – and no more than a possibility of widespread harm to people from exceedingly small amounts of insecticide, a possibility for which there is no demographic evidence and only very little inferential evidence based on effects of very large doses on mice. Those doses are enough to overwhelm a defensive system that could easily cope with amounts encountered in ordinary life. The possibility of ill effects on wild life remains and, even if it were a large one, it would have to be weighed against the alternative of ill effects on very large numbers of human beings.

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† The State Department Aid can waive the prohibition of support for insecticides not approved for use in the U.S.A. and has done so for certain insecticides (*Federal Register* vol. 42, no. 162, 22 August 1977, pp. 42272–4, and also *AID Press Notice* 77–110, 21 October 1977). The Register devotes a paragraph to the past use of dieldrin in controlling locusts in Africa. It states that research over 15 years has shown that 'The most acceptable substitute for dieldrin found to date is fenitrothion which has been used widely in Africa in recent years for control of these pests'. This reveals a misunderstanding. Fenitrothion can assuredly be used instead of dieldrin as a contact poison sprayed especially on migrating adult locusts, against which the persistent stomach action is usually of little value because they do not stop long enough to eat much. But fenitrothion cannot in fact be substituted in the most vital use of dieldrin, namely as a persistent stomach poison for relatively static hoppers when sprayed at minute doses on vegetation (*see* MacCuaig, this symposium). Dieldrin is not in fact included in the insecticides covered by the waiver and for really effective control of the locust hoppers, will have to be obtained without benefit of AID.

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Discussion

D. L. Gunn. I am asked about monitoring for resistance to insecticides in locusts. Resistance to dieldrin, as to DDT, has appeared in many insect pests, though not of course in all; as far as I know, no sign of resistance to any insecticide has yet appeared in locusts, possibly because the intensity of application, generation after generation, has not yet been enough.

M. R. Tucker (*C.O.P.R., London*). Why does Dr Gunn attach such particular importance to the use of dieldrin, in comparison for example with BHC and fenitrothion?

D. L. Gunn. Fenitrothion is an excellent contact poison, particularly for flying locusts. But hoppers are so often shielded by vegetation and by one another that no contact insecticide could be relied upon to hit enough of them. Since fenitrothion is short lived, almost every hopper not hit directly with a lethal dose would survive. Consequently we must choose a stomach poison. In this class BHC is good but it is too volatile and short lived on vegetation to last out non-feeding periods of the locusts. Moreover, it could not be used in the barrier technique, in which belts of vegetation may contain very little insecticide; bands crossing those belts soon after spraying would therefore tend to survive. Dieldrin does not suffer from these disadvantages; it lasts several weeks, declining slowly of course but also converting to photodieldrin, which is more toxic to locusts. Thus the locust hoppers can accumulate a toxic dose over rather a long time, from dieldrin on the vegetation at about 1 part/10^6, which South African tests indicate is far less than any amount likely to harm mammals. The area-dosage required to produce this is so small that the Courshee dieldrin-spraying technique is not only very effective – the only one ever repeatedly described as giving 100% kill – it is also cheap in insecticide and especially in aircraft flying time. Similarly for small-scale and localized application, the Sayer exhaust-nozzle sprayer cannot be as well served by any other insecticide. That is why dieldrin is so important.

O. M. S. Abdallahi (*OCLALAV, Dakar, Senegal*). It is useful to consider the views not only such as those of WHO but also of those directly concerned – the under-developed countries in which the pesticide is applied, where the alternative is that of dying of starvation or of dying perhaps slightly poisoned. In 1975, each time the help of OCLALAV was sought in dealing with the grasshoppers which had followed the drought, I went to the minister concerned and said ‘I have only dieldrin, which is toxic and persistent’. Invariably, each of the ministers replied ‘I prefer to attack the pests, with whatever is available: dieldrin or anything else’; they had the alternative either of seeing the crops destroyed and the populations starving, or of accepting the slight risks of poisoning. Faced with this alternative every minister had the good sense to make the same choice.

This is a point which I would particularly like to make because at the last meeting of the Friends of the Sahel, each time a *cheap* pesticide was mentioned we were told by the donors that it was not recommended. I believe that, recommended or not, this alternative must be faced:

to ask the people directly concerned how they prefer to die: of starvation, or perhaps slightly poisoned. The basic question is whether or not it is possible to save the crops. I would like to thank Dr Gunn, retrospectively, for the choice which he made some twenty years ago.

R. Le Berre (*Onchocerciasis Control Programme, Ouagadougou, Upper Volta*). I am not here as a representative of WHO; and I was myself one of the first to use dieldrin in tsetse control. But I must explain that WHO does not decree that dieldrin must not be used; countries are free to use what they wish; and I must remind M. Abdallahi that WHO is an international organization in which all countries are represented, including the member countries of OCLALAV.

D. L. Gunn. Nevertheless the U.N. Agencies (WHO and FAO) have been under pressure from the U.S.A. not to use DDT and dieldrin; freedom without money is unenviable. Does WHO nevertheless still use dieldrin and DDT?

R. Le Berre. WHO does not recommend DDT as an insecticide except for residual application within houses. That is the only exception: nothing about dieldrin, which will never be used again against tsetse flies by WHO; and, as the consumption of these insecticides will be reduced, the cost will be going up.

J. M. Castel (*OCLALAV, Dakar, Senegal*). I agree with Dr Gunn about dieldrin. As he has told us, it is only a question of dosage, and we now do a lot of work at very low field dosages, about 15–20 g active ingredient per hectare, which is really efficient. OCLALAV, like DLCOEA, holds large stocks of dieldrin, and, for locust control, an insecticide which cannot stand a number of years of tropical storage is not of much use.

J. Roy (*Locust Control & Emergency Operations, FAO, Rome*). FAO has the project, with Swedish assistance, on which Mr MacCuaig has been working with DLCOEA in Addis Ababa, to find an alternative pesticide to dieldrin against the Desert Locust; and there is a second FAO project, with Danish assistance, based in Teheran, to study residues of dieldrin and photodieldrin after field application. From the first results it appears that with the dosages we use in Desert Locust control these residues present no real danger to the environment.

H. D. Brown (*RLCS, Pretoria*). Recent political developments in southern Africa have led to a decline in international cooperative measures against the Red Locust which has responded by increased outbreaks from its breeding areas. During the past decade something like 50 adult swarms have been able to escape and seed the invasion area. In southern Africa these circumstances have resulted in the adoption of a defensive control strategy which combats the Red Locust as flying swarms in its southern invasion area. To date some 15 migrating swarms have been destroyed without any crop losses being incurred in Rhodesia and Mozambique. Modern light spray aircraft and helicopters with good maintenance backup in combination with a good communications system and extensive reporting network make it possible to effectively meet and destroy any invading swarms before they can reach crop areas. The advantages of this system are (i) the locusts are concentrated into cohesive swarms and therefore make easy spray targets, (ii) treatment of small areas by spot or placement spraying is possible with safer contact insecticides and (iii) control is relatively cheap and effective. The main problem is in locating the swarms after they have been reported because Red Locusts tend to migrate low over the ground and are not easy to spot by aerial reconnaissance.