CROP PROTECTION PROGRAMME

Optimising insecticide barriers for locust control

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Optimising insecticide barriers for locust control.

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Contents

Executive Summary

Locust outbreaks have affected farmers on all continents since agriculture began and often necessitate treating thousands of hectares with insecticidal sprays. Usually when treating locust hoppers the whole area is sprayed but an alternative is to treat only narrow strips of vegetation. These strips or 'barriers' are then encountered by gregarious hoppers as they roam around in search of food, and they consume a lethal dose of insecticide within the barrier. Although the barrier technique is not new it required research support for three reasons. Firstly there has always been a degree of guesswork about optimum barrier spacing for different species of locusts, based on their different movement and feeding characteristics. Secondly the favoured insecticide *dieldrin* was withdrawn for environmental reasons, and a more benign replacement is required with the necessary properties of effectiveness, residual action and safety. Lastly barriers required research because potentially important relative environmental advantages of using barriers versus conventional methods were poorly understood. The project has addressed these objectives in a way which aligns with DFID's development goals, by providing enhanced methods to ensure the reliability of food supplies in locust-affected countries in ways which are practical, effective and environmentally benign.

A mathematical model of the barrier technique was developed which encompasses the behaviour of different locust species to rationalise the optimal barrier width and spacing for different species and growth stages. The model demonstrated that when the probability of feeding within a barrier was taken into account, there exists an optimum rate of hopper movement which is a compromise between maximising the probability of barrier encounter in the period that the barrier remains biologically active, and the probability that a hopper will engage in feeding activity whilst inside the barrier. The optimum movement rate of the target was sensitive to the pattern of feeding activity, and a range of feeding patterns was explored. With a barrier width of 50m, the optimum distance moved by a target hopper was *c*.160m per day. The analysis suggests that species with intermediate rates of displacement form the best targets for barrier treatment.

Four candidate barrier insecticides were compared under simulated field conditions in order to recommend which might or might not be appropriate for field use. All three IGRs appeared to be sufficiently photostable to be considered suitable for barrier use, whereas the results were less clear for fipronil which rapidly degraded into two main components in the presence of strong light.

In order to assess the non-target effects of barriers, behavioural information on a range of key non target invertebrates was gathered, and an environmental monitoring exercise in Madagascar evaluated the impact of two of the pesticides on non-target organisms during emergency locust control operations during 1998. One of the products used in Madagascar and assessed in this project was deemed unsatisfactory due to effects on termites.

The model and other components of the project have produced a greater understanding of barriers, which addresses the Project Purpose which was *to develop*

control technologies to reduce the impact of significant pests (locusts) on production from cereal-based systems. Outputs will allow rational decisions on insecticide choice, deployment of barriers for different species of locust hoppers and environmental advantages of barriers versus full coverage spraying.

Background

Locust damage

Locust plagues have affected farmers on all continents since agriculture began. They are capable of devastating damage to crops and grazing areas, and when environmental conditions are favourable their numbers increase, sometimes producing devastating results. Historically this has required extensive control operations using insecticides which are usually applied as total coverage treatments, often over very large areas. Even in recession years some species of locusts and grasshoppers gregarise and threaten crops and grazing areas, so routinely require control operations using insecticides.

The barrier technique

Many operational constraints to safe and efficient locust control exist. There are often deficiencies in information, equipment and trained personnel to survey and control locusts by covering the whole area with sprays. The barrier technique involves spraying narrow strips of vegetation, termed barriers, with insecticide, rather than treating the whole area. As the barrier spraying technique is used as an alternative to full coverage or 'blanket' spraying the reduction in area treated provides logistical advantages. Compared with the tactic of finding and spraying all hopper bands individually, which is almost impossible in practice, the barrier method is easier because it removes the need for high intensity surveys. By laying down barriers the whole area is effectively 'treated', and although it is inappropriate for winged adults the technique can successfully control many species of locusts and grasshoppers at the gregarious hopper stage, which is induced by high population density. The hopper behaviour and appearance changes markedly and they become much more of a threat to crops and grazing areas. Elegantly, it is this changed behaviour which enables the barrier technique to work because hoppers roam around together in their search for grazing, and encounter the sprayed barriers. The efficacy of insecticide barriers relies on the movement and feeding behaviour of these gregarious groups or *bands* of hoppers so that they encounter the treated strips and consume a lethal dose of insecticide.

As indicated above, only relatively narrow strips of vegetation are sprayed. As the majority of the total area of vegetation remains untreated it is quicker than spraying the whole area infested by hopper bands, and easier than finding and treating all the hopper bands found in an area. Indeed Bennett and Symmons (1972) wrote that barrier spraying of persistent stomach poison is the most efficient method of hopper band control but suggested that there was a need to estimate the likely consequences of different treatments in different circumstances.

There has been uncertainty concerning the best spatial arrangement of insecticide barriers to achieve an effective compromise between high control efficacy, low control cost and low environmental impact. The spatial parameters can be described in terms of the distance between the barriers and the width of the barriers themselves, which are usually laid down in parallel lines for convenience. The objective is to use the maximum barrier separation and the minimum barrier width that provides effective control. In the past, barriers of the organochlorine insecticide dieldrin spaced at 1.25km proved completely effective against desert locust hoppers within three to 12 days (Ahmed, Abbas and Akhtar, 1964), and the Locust Handbook (Anti-Locust Research Centre, 1966) recommended that barriers for control of desert locusts could be spaced as widely as 12 km apart.

Species

In this project four important locust species were considered: desert locust (*Schistocerca gregaria*), African migratory locust (*Locusta migratoria migratoriodes*), brown locust (*Locusta pardalina*) and red locust (*Nomadacris septemfasciata*). These are not the only species for which barriers are appropriate and indeed several grasshoppers of occasional economic importance also gregarise. Data on the four species which were incorporated into the model was gathered from the locust archives held at NRI, and includes reports published as Anti-Locust Bulletins as well as journal articles. The available data on behaviour of other locust species are not sufficiently complete to incorporate into the model.

Barrier insecticides

Choice of insecticide is critical because barriers must remain active for several weeks. Quickly inactivated molecules of the type used for existing locust control spraying such as fenitrothion would be inappropriate, and until the chlorinated hydrocarbon insecticides were withdrawn from use they were effective. Dieldrin was the barrier insecticide of choice because of its persistence. Unfortunately environmental accumulation, which was having an effect on non target species such as birds caused the organochlorine insecticides to be withdrawn. Now more modern replacement insecticides are required for barrier use which have suitable characteristics such as relative stability and acceptably low mammalian toxicity. Cooper et al. (1995) concluded that the insect growth regulator (IGR) diflubenzuron was a potentially useful replacement for dieldrin, and there are several other insecticides that might be equally good or better barrier candidates. In this work the IGRs teflubenzuron, triflumuron and diflubenzuron were compared with fipronil, an insecticide with a more conventional mode of action. Sunlight is an important factor in degradation of insecticides and rapidly renders them inactive. In this project simulated solar degradation was used as a measure of the robustness of the molecules and relative field persistence. Survival under powerful artificial light was used as a means of comparing their suitability as barrier insecticides.

Environmental factors

Widespread use of relatively non-specific insecticides has potential direct consequences for non target invertebrates and secondary ones for the animals for which they form a diet component. With barrier insecticides a balance is needed between rapid degradation and long term persistence. The organochlorine insecticide dieldrin was persistent in the field and also accumulated in the bodies of the target species, which would have been ideal had it not also survived and accumulated in some food chains. Predators accumulated an increasing concentration of dieldrin within their bodies in line with other reported consequences of organochlorine molecules, which include loss of breeding success in predatory birds. Any replacement barrier insecticide should not accumulate in this way, nor be devastating for important non target species such as insects, spiders and higher animals. A review of non target effects was made for some important genera, and specifically the behavioural characteristics which prepose sensitivity to locust control operations. Additionally a study was made in Madagascar during a locust outbreak when large amounts of insecticide were being used to bring the problem under control. Non target effects of two of the insecticides being used - triflumuron and fipronil were compared and evaluated. These insecticides were being used by the national programme and this DFID-funded project carried out some of the work in the form of an 'add-on' proposal to the main project. Several other agencies which included USAID and GTZ also contributed to the funding of the work in Madagascar.

Project Purpose

The project purpose was to develop control technologies to reduce the impact of locusts on agricultural production. Locusts are sporadic but serious pests capable of devastating production within arid and semi-arid regions. When they occur they are a constraint to agricultural production and outbreaks can set back the development potential of a region, so there is a need to mobilise plant protection departments rapidly in order to apply control measures. A key constraint to effective control can be the difficulty in finding hopper bands in an infested area in order to spray them. To a large extent the barrier technique overcomes this by obviating the need to find individual bands. The resulting control from using barriers is not instantaneous, but takes several days due to the need for hopper bands to encounter sprayed barriers. However, unless the bands are threatening crops the technique provides effective control with minimum quantities of pesticide. Nor is it necessary to find all the hopper bands - It is only necessary to define the area requiring treatment then lay down barriers of insecticide on vegetation which will eventually control a high proportion of the population.

Research Activities

The research comprised four main components; development of a model to optimise barrier spacing for four species of locusts, assessment of the environmental impact of barriers on key non-target species, evaluation of short term impact on non-target organisms of two pesticides used during emergency locust control operations in Madagascar, and studies of photodegradation on four candidate barrier insecticides as a means of comparing likely field persistence. Each is reported briefly here and more detailed reports form the appendices to this document.

- Development of a model to optimise barrier spacing for four species of locusts.
- Assessment of the environmental impact of barriers on key non-target species.
- Evaluation of short term impact on non-target organisms of two pesticides used during emergency locust control operations in Madagascar.
- Provision of photodegradation data on four candidate barrier insecticides as a means of comparing likely field robustness and persistence.

Outputs

1. Production of a model to optimise barrier spacing for four species of locusts.

The central aim of this projects was to develop a mathematical model of the barrier technique which encompasses the behaviour of different locust species to rationalise the optimal width and spacing for different species and growth stages. Bennett and Symmons (1972) wrote that barrier spraying of persistent stomach poison is the most efficient method of hopper band control but suggested that there was a need to estimate the likely consequences of different treatments in different circumstances. The effectiveness of insecticide barriers against locust hopper bands depends on a number of factors which interact over time: the movement and feeding activity of the hoppers, the degradation of the pesticide, and the relationship between insecticide dose and hopper mortality. Treating only a fraction of the locust-affected area has both economic and environmental benefits (Dobson et al., 1997) but there has been uncertainty concerning the spatial arrangement of insecticide barriers to achieve an effective compromise between high control efficacy, low control cost and low environmental impact. For logistical reasons, especially when applied by aircraft, barriers are usually deployed as a series of parallel strips. Their spatial arrangement can therefore be described in terms of the distance between the barriers and the width of the barriers themselves. The objective is to use the maximum barrier separation and the minimum barrier width that provides effective control. Four important locust species were considered: desert locust (*Schistocerca gregaria*), African migratory locust (*Locusta migratoria migratoriodes*), brown locust (*Locusta pardalina*) and red locust (*Nomadacris septemfasciata*). The movement of the hoppers is a determinant both of barrier encounter rate and of the time spent in a barrier. The efficacy of a barrier treatment is likely therefore to differ between locust species and instars. Only that component of movement perpendicular to the axis of the barriers will lead to barrier encounter. Not only the rate of hopper movement therefore but also the orientation and rate of turning will affect barrier encounter. This differs between species and is also dependent on the habitat and the food supply available to the hoppers (Chapman, 1957; Dean, 1967; Steedman,1988). It might be expected that insecticide barriers might be most effective for locust hoppers which reliably march significant distances. There is some variation in reported data on speed and distance marched for different species, and these data were averaged for the model. The pattern of hopper feeding activity determines the probability that a hopper will ingest insecticide during its passage though a barrier. The main mode of action of insect growth regulators is by ingestion, though some contact action can occur in some cases (Graf, 1993). The number of feeding bouts engaged in by a hopper within a barrier depends on the mean distance walked between feeding bouts and on the width of the barrier. The interval between feeding bouts is related to the rate of passage of food through the alimentary tract (Ellis, 1963) as well as the availability of vegetation (Chapman, 1957). The amount of food (and therefore insecticide) ingested is approximately proportional to instar weight: daily vegetation consumption in *S. gregaria* hoppers is just over one tenth of body weight (Davey, 1954). The model was used to assess suitability of different locust targets for barrier treatment. Simulations allowed a prediction to be made of the total mortality of hoppers during the period of biological activity of the barrier. The sensitivity of predicted mortality to changes in parameter values was examined over a range of values for each parameter. There was an optimum movement rate at which the kill of hoppers was maximised. If the hoppers moved too much then they were more likely to pass through barriers without feeding. There was therefore an interaction between the optimum rate of movement (to maximise kill) and the frequency of feeding. If feeding frequency was high then kill was optimised at a higher movement rate than when feeding frequency was low. This optimum movement is the best compromise between maximising the probability of barrier encounter in the period that the barrier remains biologically active, and the probability that a hopper will engage in feeding activity whist within the barrier.

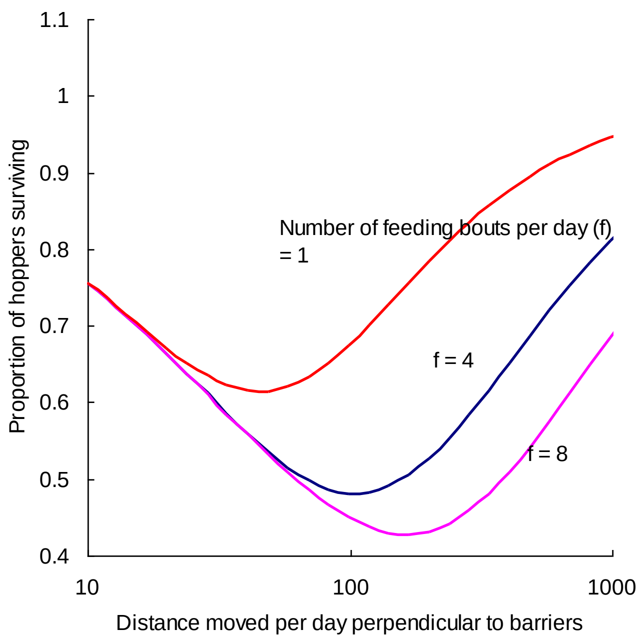

Fig. 1. The effect of distance moved by, and the feeding behaviour of the hoppers on the proportion surviving barrier treatment (based on an inter-barrier space of 1000m, barrier width *of* 50m and daily degradation of the insecticide of 0.1).

The optimum movement rate of the target was sensitive to the pattern of feeding activity. A range of feeding patterns was explored, and with a barrier width of 50m, the optimum distance moved by a target hopper was c.160m day^{-1}. In the example shown in Fig. 1, the optimum movement distance varied between 50 and 170m per day depending on the number of feeding bouts engaged in by the locust hoppers. The analysis suggested that species with intermediate rates of displacement form the best targets for barrier treatment. These include later instars of *S. gregaria* and L. *migratoria* migratoides in dense vegetation (estimated daily displacements of 127 and 64 m, respectively, with an estimated twelve feeding bouts), and L. pardalina and *N.*

septemfasciata in sparse vegetation (estimated daily displacements of 127 m and 4 feeding bouts, for both species).

2. Assessment of the environmental impact of barriers on key non-target species.

In general, IGRs appear to present a lower environmental hazard from a toxicological point of view than conventional insecticides presently used for migratory pest control (Murphy et al., 1994). The risk to all terrestrial vertebrate animals is lower from IGRs (used at recommended rates for caterpillar pest control) than from all conventional insecticides currently used at recommended rates for locust control (Eisler, 1993). When coupled with use of the barrier spraying technique, IGRs would appear to offer an environmentally benign method of chemical locust control. The new insecticide fipronil has also been suggested as suitable for barrier spraying. Relatively little was known of the non-target impacts of this insecticide, but results to date suggest that it is quite hazardous for non-target invertebrates (Balança & De Visscher, 1996; van der Valk et al., 1998; Lahr et al., 1998). However, effectiveness and efficiency against the target and implications for non-target organisms will all be affected by the specific parameters of barrier spacing, etc. From work done to date on impacts of IGRs and fipronil on non-target inverts, the key groups seem to be as follows:

Caterpillars (Lepidoptera larvae: Noctuidae in particular)
Spiders (Araneidae; Oxyopidae (*Oxyopes* sp.); Thomisidae; Lycosidae) – immatures in particular
Non-target grasshoppers (Acrididae), crickets (Gryllidae) and possibly katydids (Tettigoniidae)
Ground beetles (Carabidae & Tenebrionidae)
Termites (Isoptera: *Coarctotermes* spp.)
Diptera (Asilidae)
Parasites (Hymenoptera: Braconidae)

This list was drawn up from studies on barrier spraying in Madagascar (Tingle, 1996; Tingle & McWilliam, 1998; 1999; 2000) and other work on non-target impacts of locust control using blanket sprayed insecticides (Balança & De Visscher, 1996; 1997a; 1997b; Everts et al., 1997; 1998a; 1998b). Other outbreak areas for other locust spp. will have different non-target fauna. Thus the main list will be supplemented by guestimates/knowledge from other areas likely to be sprayed for locust control. Other factors also need to be taken into account. For example, with benzoyl urea IGRs it is only immature stages which will be directly affected (although adult females may lay non-viable eggs after treatment with these IGRs). Thus for most groups data will be required on movement and feeding rates of immatures.
For fipronil, the story is entirely different. Adults are affected by fipronil. Thus rates of movement and distance moved by adults may also be important.

Termites give added problems. Data from Madagascar suggest that it is worker termites which collect contaminated forage and return it to the nest (Rafanomezana, 2000), where it is then fed to immatures and to the queen, which has the potential to severely affect colony health. Thus for termites, the crucial factors will be number of foraging bouts made over time, and distance over which they forage in order to get some sort of measure of amount of vegetation harvested and thus potential volume of insecticide fed to the colony. Diptera provide different problems. Again it is only larvae that will be susceptible to the IGRs. Parasitic wasps also have potential problems. As they will (in the case of Braconids) be largely parasites of lepidoptera larvae, it will probably be a question of how far the host moves and how much it feeds. Data on reductions in feeding and movements in parasitised hosts may help. As with all non-target species, knowledge of the biology of the various key-groups is needed in order to interpret what will happen when different forms of locust spraying are carried out.

Barrier spraying and the environment

The only research carried out on the environmental impact of barrier spraying operations for locust control has been that in Madagascar, see 3 below. Early work with diflubenzuron barrier sprays showed clearly that for some of the most highly sensitive non-target groups (caterpillars, for example) barrier spraying did provide a true unsprayed refuge (Tingle, 1996; 1997a). However, for other non-target groups (non-target grasshoppers, for example) the value of barrier spraying in providing unsprayed refuges was unclear (Tingle, 1996). Circumstantial evidence does also point to benefits for grasshoppers from barrier-spraying (Tingle, in prep.b). Later work on triflumuron and fipronil barrier sprays showed similar discrepancies in the value of the inter-barrier spaces as true refuges for non-target organisms. The effects of barrier sprays with these two insecticides on vertebrate fauna is described in the appended report (Tingle & McWilliam, 1999) There was very clear evidence of the value of inter-barrier spaces for termites in the area sprayed with fipronil (Tingle & McWilliam, 1999; Tingle & Dewhurst, 1999; Tingle et al., in prep) and to a lesser extent with triflumuron (Tingle & Dewhurst, 1999). There was also evidence of the value of inter-barrier spaces for spiders (particularly immatures) and possibly crickets, from negative impacts of fipronil and for spiders (particularly Lycosidae) and beetles (particularly Tenebrionidae) from negative impacts of the IGR (although only in savannah areas) (Tingle & McWilliam, 1999). Although there is no direct evidence, there may be some reduction in effects on flies from barrier spraying with fipronil over cover spraying with the same insecticide (Tingle & Rahamefiarisoa, 2000).

Published data on behaviour of non target species are given in the accompanying report in regard to walking speed, distance moved in a day, and feeding rates. The findings were that terrestrial invertebrates, particularly mandibulate herbivores, but also certain parasitic wasps and predatory beetles are adversely affected by IGRs and minor impacts on spiders and plant feeding bugs cannot be discounted. Fipronil affects termites, spiders and non-target grasshoppers and may also have adverse impacts on certain flies and beetles. Graphs are presented in the report showing changes in relative abundance of these “key” invertebrate groups following barrier spraying with diflubenzuron, triflumuron and fipronil in Madagascar.

Caterpillars (Lepidopteran larvae) and non-target grasshoppers showed severe short-term, adverse impacts from diflubenzuron, depending on timing of spray applications (Tingle, 1996). Early spraying (mid-February) affected non-target grasshoppers adversely, whereas later spraying (end March) adversely affected caterpillars. Spiders, Braconid wasps and crickets also showed indications of adverse effects from this IGR (Tingle, 1997b; 1997c; in prep.a).

3. Evaluation of short term impact on non-target organisms of two pesticides used during emergency locust control operations in Madagascar.

Early in 1998, an environmental monitoring programme was established to evaluate the impact of emergency locust control operations using the two insecticides fipronil and triflumuron, barrier sprayed for hopper band control, in an area of savannah grassland near Ankazoabo, south west Madagascar. The monitoring programme was limited to fipronil and triflumuron as these are the insecticides likely to be used most extensively (being used in preventative as well as emergency operations). This study has demonstrated that it is possible to successfully monitor emergency locust control operations and their environmental impact (Tingle & McWilliam, 1999). The spray operations which were monitored followed recommended practices and dose rates. During emergency operations, such a high level of accuracy will not always happen in reality.

The most significant conclusion from this study for the non-target fauna is the extent of negative impact of fipronil on termite populations, which appears to be very severe. Apart from this severe impact on termites, it appears that when applied in barriers, fipronil generally affects fewer non-target invertebrates than the IGR triflumuron and it has relatively minor adverse effects (Tingle & McWilliam, 1999). Immature spiders, non-target grasshoppers and flies [Diptera] were the other terrestrial invertebrates which showed indications of adverse, short-term impacts. Work on triflumuron confirms evidence of some minor adverse impacts of barrier sprayed IGRs on the relative abundance of spiders, grasshoppers, crickets and caterpillars, with termites also affected in the short-term. No firm conclusions can be made as to the impact of spraying in the longer term until monitoring has been carried out through at least one rainy season and analysis extended to other species.

From this initial assessment of the short-term impacts of emergency locust control, both the insecticides studied show some adverse impacts on non-target wildlife even when barrier sprayed. For any future studies, termites have been identified as sensitive indicators of adverse impacts of fipronil. Lepidoptera larvae, non-target grasshoppers and several families and species of spider have been confirmed as good indicators of adverse impacts of benzoyl-urea IGRs. Triflumuron appears to present less environmental risk than fipronil, due to the severe impact of fipronil on termites which are a keystone group in the ecology of the savannah grasslands of S.W. Madagascar. Fipronil cannot be considered as the insecticide of choice for barrier spraying for locust control from an environmental point of view and, following the precautionary principle, it's use should be suspended until the ecological implications of its adverse impact on termite colonies (and possible effects on some birds and lizards) have been determined (Tingle, 1999).

Recommendations are given in more detail in the report, but in summary it was found in Madagascar that the IGR being used had only minor adverse effects on a range of non-target invertebrates. The more important finding was that fipronil had severe effects on termites, and given their importance in nutrient recycling, soil structure and water infiltration, and as a food source for higher animals, it was recommended that donors should encourage the withdrawal of fipronil from use as an insecticide for barrier spraying with immediate effect. The following recommendations were made:

- To minimise the environmental risk, a benzoyl-urea IGR is recommended for use in barrier-spraying operations for locust control.
- Donors should encourage the withdrawal of fipronil from use as an insecticide for barrier spraying in Madagascar with immediate effect.
- If (following further studies) fipronil is re-instated, further non target studies should include termites, bees, spiders and higher animals such as certain birds and the native tenrec.
- Environmental monitoring should be an essential component of aid given for locust control.
- Choice of product for locust control should follow best practice.

4. Photodegradation data on four candidate barrier insecticides as a means of comparing likely field robustness and persistence.

Four formulated pesticides, see below, which were considered to be possible replacements for dieldrin as insecticides used in barrier spraying were used in these tests. The insecticides subjected to simulated solar radiation in a Heraeus Suntest machine, an apparatus developed for the clothing industry to accelerate fading of dyes which uses a high pressure xenon source of light, to assess their stability. In previous work (Moore et al 1993) similar units have been used to test the sunlight stability of formulated insect pathogenic pesticides and the effectiveness of screening agents in reducing light-induced degradation. Photodegradation is recognised as being important in the breakdown of pesticides alongside oxidation, hydrolysis and adsorption to surfaces accounts for further loss of activity in the field. Photodegradation was used as a comparative measure of the field life of the test insecticides which were:

(i)	Diflubenzuron	(trade name Dimilin)
(ii)	Teflubenzuron	(trade name Nomolt)
(iii)	Triflumuron	(trade name Alsystin)
(iv)	Fipronil	(trade name Adonis)

In the first tests the undiluted formulation was applied as either discrete drops or smeared onto a microscope slide which had been washed in alcohol. Tests showed that when slides with the IGRs were exposed to a mixture of 80:20 dichloromethane:hexane in an ultrasonic bath for 20 minutes the insecticide was removed satisfactorily. ULV sprays are not diluted before being sprayed so the test using the concentrates were appropriate. A slightly different washing method was used for fipronil, (full details are in the accompanying report) in which the two solvents were used separately. For chemical analysis a comparison of gas liquid chromatography (GLC) with high performance liquid chromatography (HPLC) showed the latter to be more effective, and HPLC reduced interference of co-extractives. Further details on equipment are given in the report. The sample responses were compared with both an analytical standard and the 1 hour exposure samples. Responses were measured using the area value for the sample peak unless interference was apparent. In these cases the peak height response was used instead. As with all analytical work, when handling and treating the samples great care was taken to avoid cross contamination between samples.

When used in field control operations they will be exposed to sunlight periods averaging up to 12 hours per day and will experience periods of cooling. Temperatures in the solar simulation unit remain approximately constant at around 40°C after the unit has warmed up and stabilised. Persistence on a vegetative surface may also be affected by the degree of adsorption associated with the nature of the surface, including moisture content. Under natural conditions leaf surfaces will be dry, unless there is rainfall, but some moisture may be deposited as dew. The moisture in/on vegetative surfaces may also be replenished through natural internal fluid transportation, whereas the vegetative surfaces used in these experiments dried relatively quickly in the solar simulation unit and were completely dry after 12 hours. Any effects due to the retention, preservation or loss of residues through co-distillation of residues with water arising from the presence moisture in or on the leaf will not have been reflected by these tests. However they are a useful comparison of stability and robustness, and as such a measure suitability of the insecticides for barrier use.

Diflubenzuron	**Teflubenzuron**	**Triflumuron**	**Fipronil**
1 Hour			57
3 Hour	100	106	
12 Hour	82	90	32
24 Hour	88	114	10
48 Hour	97	102	1.2
120 Hour	81	95	Not pursued
240 Hour	92	79	Not pursued
480 Hour	82	93	Not pursued

Table 1 Percentage of the original chemical remaining after periods up to 480 hours (20 days) exposure to simulated sunlight.

The recommendations are summarised overleaf, and given in more detail in the accompanying report.

- All three IGRs tested appear to be sufficiently stable for use as barrier insecticides and although the test was only a comparative measure, and not a true reflection of the persistence in the field they showed remarkable photostability under the experimental conditions of the tests.
- Fipronil was the exception and rapidly formed several breakdown products under the simulated solar conditions. As such it would not be recommended for use in barriers.

Contribution of Outputs

This research harmonises with DFIDs aims of reducing losses due to pests in a way which is environmentally sustainable by improving the understanding of a technique which is efficient and effective for controlling gregarious hoppers. The findings will allow hopper-infested areas, which can be extremely extensive, to be managed in a way which is effective, practical and potentially less damaging than either full coverage spraying or reliance on organochlorine insecticides. The sensitive non-target species which are at risk from locust control operations have been identified, and field assessments linked to a literature review on behaviour have indicated that the combination of IGRs with the barrier technique is relatively benign for the environment. The reasons for this are that IGRs are innately less toxic than alternative pesticides and that the barriers are only applied to a fraction of the 'treated' area. By relating the geometric parameters of the barrier to the species of locust being controlled the barrier technique can now go forward on the basis of research-backed rationale, rather than empirical iterative experiments which are difficult on pests which are both mobile and sporadic.

Promotion

The provision of papers and reports to the national and multinational agencies involved in locust control operations directly, or in the funding of such operations, is the major promotion pathway. Since the withdrawal of dieldrin the area treated using barriers is believed to have fallen markedly and the agencies concerned with locust control will no doubt wish to validate the hypotheses developed in this project by carrying out field trials. The authors are currently considering making a proposal to the DFID Crop Protection Programme to assist in this process.

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List of appendices

Appendix 1 A model to compare the suitability of locust hopper targets for control by insecticide barriers

Appendix 2 Report on the impact of spray barriers on non-target invertebrates.

Appendix 3 Evaluation of short term impact on non-target organisms of two pesticides used during emergency locust control operations in madagascar.

Appendix 4 Report on the assessment of the stability of fipronil and various insect growth regulators to simulated sunlight.

Appendix 5 Inventory Control Form

Appendix 5
Inventory Control Form

NRIL Contract Number: ZA0228...
DFID Contract Number: R7065
Project Title: Optimising insecticide barriers for locust control
Project Leader: J Cooper

[List all single equipment items with a purchase value higher than £500 and items with a purchase value lower than £500 but deemeed to be of an attractive nature (i.e. cameras, motorcycles, etc.) purchased during the quarter.]

Please fill in ALL the information requested in the table below for each item

Item	Make and Model	Serial No.	Date received	Purchase price	Location	Disposal		
						To	Date	Authorised
Desktop computer	Dell GXA 233 Mhz	MN886	February 1998	£1438	NRI room B269			

Recommendation: Although the value of the PC has fallen since the purchase date to an estimated £400 it is still a useful tool. If retained by Dr J Holt the computer can be used to further refine the barrier model and demonstrated to visitors from locust-affected countries and students wishing to study migratory pest control. Dr Holt has a submission with CPP for a project modelling and predicting armyworm outbreaks. The PC would be useful for this project. I recommend that the PC be retained within NRI for this purpose.