A Review of the Current Knowledge on Pesticide Application Techniques Related to Desert Locust Control

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Improving Pesticide Application Techniques for Desert Locust Control

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INTRODUCTION

Prior to the development of insecticides, the only crop protection options open to farmers whose crops were being attacked by locusts were mechanical - beating them with sticks, digging trenches for them to fall into, lighting fires to produce repellent smoke. These methods can protect crops from light infestations, but are often futile when infestations are heavy, and make no impact on the overall locust population in the region. In an attempt at more strategic control, locust eggs in the ground are sometimes dug or ploughed up, but this is laborious work and it is difficult to find many of the locust egg beds without very good information on where swarms have been seen laying.

From the 1950s to the mid-1980s, the technique of choice for control of the Desert Locust involved the spraying of barriers of persistent organochlorine insecticides (dieldrin) across areas infested by hopper bands. Even insects which encountered the sprayed vegetation weeks later could be killed by such barriers. This technique was very forgiving of application timing and spatial accuracy and was economical because of the small proportion of land area actually sprayed. However, due to problems with the use of dieldrin in other fields of crop protection and public health such as high mammalian toxicity and bio-accumulation, it was withdrawn from use in most countries and donors will not now fund its purchase or support its use, thus eliminating barrier spraying as an option in the last decade or so.

Since the withdrawal of dieldrin, locust control has become more difficult and less efficient - in the absence of this product, other less persistent pesticides have had to be sprayed or dusted directly onto hopper bands and swarms, or distributed close to them as baits. All of these techniques require far greater effort in locating and treating individual targets than the old barrier technique which had apparently worked so well.

While it is clear that certain principles apply to all current Desert Locust control and to a certain extent to other locusts and grasshopper control, in practice the approaches taken vary widely from place to place. This is partly a reflection of the widely varying circumstances which prevail at different sites, times and seasons, but also partly due to arbitrarily-developed habits and practices used by particular staff and organisations. Control is sometimes done in a certain way without staff knowing the origin of the practice or its explanation. At other times, methods are determined more by the constraints, such as lack of appropriate equipment, materials, knowledge and training, rather than by any positive decisions on optimal practice. It seems that most Desert Locust control is much less efficient and safe than it could be.

Addressing these problems is made more difficult for management staff by the scarcity of detailed information on exactly what is being done in the field - feedback is usually poor due to the fact that most locust control operations take place in a great hurry in remote locations, with responsibilities delegated to staff who are not trained in monitoring and reporting.

There is a clear need for guidance on what to do in particular circumstances and the FAO Desert Locust Control Guidelines go some way towards providing this. However, the problems remain of acquiring more feedback on what is actually happening in the field (monitoring systems required), promoting take-up of the advice in the Guidelines (training, staff management) and deciding how to improve the advice where it is incomplete or based on little more than speculation (research required).

The aim of this review is to catalogue, to the best of the author's ability, the range of technologies and methodologies used for Desert Locust control in order to highlight problems, constraints and knowledge gaps in implementing safe and efficient locust control. The areas which may respond to research and training can then be identified. In some sections, the current advice given by FAO in its Desert Locust Guideline series is summarised under the heading 'Advice' and below it is the author's interpretation of what is actually being done in the field under the heading 'Practice'.

CHAPTER 1. TECHNOLOGY USED FOR DESERT LOCUST CONTROL

Control products

There are several different types of insecticidal or behaviour-modifying products of potential use in locust control. They can be differentiated by their mode of action: Conventional insecticides including organochlorines, organophosphates, carbamates, pyrethroids and phenylpyrazoles act on the nervous system of the insect in various ways (neurotoxic). They are relatively fast and reliable, but full cover spraying is usually required, except in some cases where long persistence on vegetation allows them to be used for barrier spraying. Some are relatively hazardous to operators and environment. See Table 1 below for brief details on different types of conventional insecticide. Insect growth regulators (IGRs) on the other hand work by disrupting the moulting process so that the insect dies in the moult. This means that they are slower acting and are not effective against adults, but their persistence allows them to be used as barrier sprays, and they are relatively safe to operator and environment. Botanical products extracted from plants may kill, repel or inhibit feeding, but they have slow action and kill is often incomplete. Semiochemicals include pheromones which may produce useful behavioural or developmental changes in locusts such as reversing gregarisation, but they do not kill directly. Various natural microorganisms infect locusts in the field and the possibility exists of using one of these or an agent from elsewhere to infect and kill them - see Box 1. An attractive goal is establishing an infection in a locust population which is passed from locust to locust if the conditions are suitable. This 'cycling' of infection might mean that it is not necessary to spray all locusts in an infestation to kill the whole population, and that the infection may persist, suppressing locust numbers over a period of time. Microbial pesticides (also known as biopesticides) are slow-acting at present, but very safe to operators and environment. There exists the possibility with some microbial pesticides of local prodction, possibly reducing the costs associated with pesticide use against Desert Locust. However, a problem with local production is that quality control is often not as rigorous as it should be, leading to poor field results or the production of contaminants.

Table 1 Summary of advantages and disadvantage of different types of insecticide

Advantages	Disadvantages
Organochlorines e.g. dieldrin, DDT, BHC	
• Persistent so can be used for barrier spraying	• Some have high mammalian toxicity • Some accumulate in animals' bodies, concentrate in food chains and are thus hazardous to the environment • These products are withdrawn from use by most donor countries and funds are not allowed to be used either to purchase them or to support their use.

Organophosphates and carbamates e.g. fenitrothion and bendiocarb	
• Medium mammalian toxicity • Quite fast acting (2-8 hrs) • Some are low cost and/or are locally manufactured	• Some still dangerous to mammals • Some kill birds and fish • Broad spectrum
Pyrethroids e.g. deltamethrin, lambdacyhalothrin	
• Fast 'knock down' • Low mammalian toxicity	• Locusts may recover after 'knockdown' • Broad spectrum
Phenylpyrazoles e.g. fipronil	
• Persistent - can be used in barriers • Formulations have relatively low mammalian toxicity	• Relatively slow at low doses (1-2 days) • Broad spectrum - many other arthropods are affected, as well as some other organisms
Mixtures or 'cocktails' of conventional product e.g. fenitrothion plus esfenvalerate	
• Combine good features of two insecticides	• More complicated to calculate dose and calibrate
Insect Growth Regulators (IGR) e.g. diflubenzuron and teflubenzuron	
• Persistent- can be used in barriers • Very low mammalian toxicity • Quite low environmental impact • Selective due to stomach action	• Slow action (>3 days) • Little effect on adult locusts, although some ovicidal activity • Harmful effects on freshwater arthropods
Botanicals e.g. neem	
• Produciton at village level in small quantities may be possible	• Slow action and incomplete kill • May be inconsistent quality • Limited commercial availability
Semiochemicals e.g. locust aggregation pheromone	
• Pheromones may be highly specific and safe products	• No direct kill but modify behaviour • None available commercially
Microbial Pesticides e.g. Metarhizium spp, Beauvaria spp, Nosema spp.	
• Specific therefore safe to operators and environment. • Produced at village level?	• Slow action and sometimes poor kill. • May have short shelf life or formulation difficulties. • Difficult to produce in large quantities rapidly • May be quarantine issues in importing to new countries • May be quality control issues with local production

Box 1. Microbial Pesticides which have been investigated include:

- bacteria - no *Bacillus thuringiensis* (BT) strains have been found to be effective against locusts and some other bacteria which infect locusts may be harmful to man.
- viruses - there are some entomopox viruses which infect locusts but they have not been shown to have useful efficacy in the field. They are also expensive to produce since they are made 'in vivo' i.e. in live insects
- protozoa - some protozoa such as *Nosema locustae* can kill locusts and grasshoppers but they have disappointing efficacy in the field
- fungi - mitosporic fungi such as *Metarhizium* spp. have been the most successful of the microbial pesticides tested so far. They can be produced 'in vitro' i.e. in non-living materials, by a solid state fermentation process with simple materials. *Metarhizium flavoviride* has good contact action, unlike any of the other candidate biopesticides and a strain is being developed as a product known as 'Green Muscle'. *Beauvaria bassiana* has also shown some success, but may be more effective in temperate climates since it is inactivated at high temperatures.

Advice Individual products from all the groups of neurotoxic insecticides, from the IGRs and one microbial pesticide have been demonstrated to be effective in trials validated by the FAO Pesticide Referee Group. A verified effective dose for these is published in the FAO Desert Locust Control Guidelines and in the Reports of the Pesticide Referee Group. Copies of these are available in three languages (English, Arabic and French) from FAO on request. Information is also given, in these sources, on speed of action, mammalian toxicity and environmental impact for various classes of organism. In choosing which product to buy and use, these data, along with other factors such as cost and availability, can be used to select a product which is most appropriate for the particular control situations envisaged. Account should be taken of human and environmental safety, especially if there are ecologically sensitive areas nearby.

Practice Choice of product often depends on who is paying for it. If it is being bought by the Government of the locust-affected country, choice may be constrained by registration restrictions in that country and availability of hard currency for imports. There may also be a tradition of using a particular pesticide and formulation with which control staff are familiar and for which sprayer settings are known. If it is being bought by the international donor community, registration restriction should also apply, but suitable products can be purchased and freighted from anywhere in the world. If the product is being bought by FAO for a country with funds provided by donors through FAO, the pesticide selected generally **must**

be listed by the Pesticide Referee Group as efficacious against Desert Locust and **must** comply with national registration regulations. Availability at short notice is usually an important factor in the decision, as is cost, but donors are also more likely to take account of human and environmental safety in their choice. There is also sometimes a tendency to be swayed by national/donor commercial self-interest.

An important aspect of the previous dieldrin-based technique was for locust-affected countries to hold large stocks of the product. These deteriorated in storage and there is now an international effort to tackle the problem of the disposal of these obsolete pesticides. One of the benefits of having a larger list of effective products is that many have alternative uses in other branches of agriculture. If the ULV formulations are not used for locust control, there is the possibility of using them for other agricultural purposes or of re-formulating before the expiry date for use on other pests of agricultural or public health importance.

Formulations

Formulation is the manner in which the active ingredient is mixed with other substances to produce the product which is bought or used.

Baits

These consist of a carrier such as maize meal or wheat bran, impregnated with an insecticide such as bendiocarb, and scattered near the locusts hoppers by hand or sometimes by aircraft. The hoppers eat the bait and are killed. This method was popular in the 1960s, but has been used less in recent years. A big disadvantage of this method is the amount of work involved in preparing, transporting and applying the large quantities of bait (5 - 15 kg/ha for marching bands and over 50 kg/ha for settled hoppers and adults). The technique also poses danger to non-target animals that may eat the bait.

Dusts

These comprise a fine inert carrier such as powdered chalk or talc mixed with insecticide, which is then scattered onto hopper bands. Like baiting, insecticide dusting has the advantage that it can be carried out without specialist application equipment - a hessian bag of dust beaten with a stick has commonly been used. There are also manual and motorised dusters, some of which can be mounted on vehicles. Many countries have given up dusting due to the large quantities of product to be transported and applied (up to 10 kg/ha), and to the fact that control is sometimes poor especially with later instar hoppers and adults. If the ‘inert’ carrier is too alkaline, there may also be a problem with breakdown of the insecticide active ingredient in storage. There is also a health risk for operators as the dust is easy to inhale. The technique is not recommended anymore by the Pesticide Referee Group.

Sprays

Liquid sprays are the most commonly used formulation for locust control. Spraying involves atomising a liquid pesticide i.e. breaking it into droplets, which are distributed over the target area. Spraying can be divided into two broad types.

- Water-based spraying is common in conventional agricultural crop protection. It usually involves applying hundreds of litres of insecticide/water mixture per hectare. The insecticide formulation i.e. the mixture supplied by the manufacturer, is usually an emulsifiable concentrate (EC), but may also be a wettable powder (WP). Application is by conventional field crop sprayers, i.e. either lever-operated knapsack sprayer, vehicle-mounted airblast sprayer, or aircraft-mounted boom and nozzle equipment. The droplets produced are relatively large and fall quickly to the ground. This sort of spraying is rarely carried out on a large scale against Desert Locusts because the work rate (number of hectares treated per hour) is slow and the large volumes of clean water are often difficult to find, transport and apply during locust operations.

- A technique using much smaller quantities of spray liquid, called ultra low volume (ULV) spraying, was initially developed in the 1950s for use against the Desert Locust, and is now the most efficient method available - see Box 2. It involves applying between 0.5 - 3 litres of spray liquid per hectare, although for ULV locust control, between 0.5 and 1.0 l/ha is preferred. This small quantity of concentrated insecticide is not mixed with water or any other liquid - the special ULV formulation is supplied ready to spray. In order to spread this very small volume over each hectare, the liquid must be broken up into small droplets light enough to be carried easily by the wind. To prevent these small droplets evaporating in the hot conditions which are typical during locust control operations, ULV sprays are based on oil rather than other solvents which may be too volatile. These small droplets do not deposit (land on surfaces) very easily. They fall very slowly, so tend to be carried sideways by the wind and not to sediment (‘rain down’) onto horizontal surfaces. In addition, if they are too small or the wind is too light, they tend to go round objects rather than to hit them, somewhat like smoke. However, if the droplets are the right size and there is sufficient wind, they impact onto vertical surfaces such as vegetation or locusts. Application is usually done with specialist ULV spray equipment which can be portable, vehicle, or aircraft-mounted.

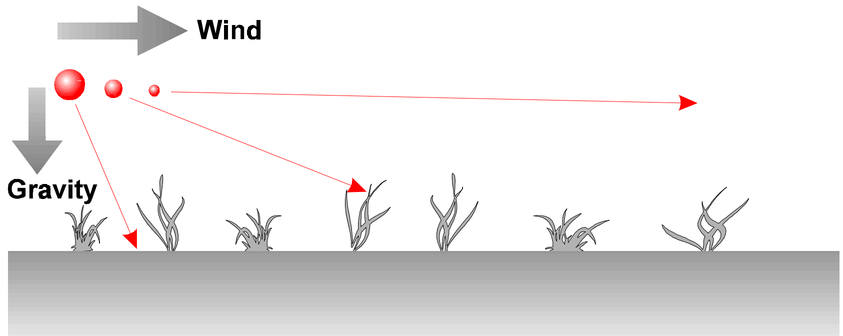

Figure 1 Influence of droplet size on their downwind movement

Box 2. Summary of characteristics of ULV spraying

- very low volumes (0.5 - 3 l/ha) compared with hundreds or thousands of litres/ha for water-based spraying
- droplets are small and of a relatively uniform size
- formulations are oil-based to prevent the small droplets evaporating
- no mixing is required - the ULV formulation is usually sprayed as it is
- a wind over 1-2m/s is required to carry droplets over the spray area and to impact them on the target.
- some formulations are quite concentrated

Table 2 Summary of advantages and disadvantage of different types of formulation

Advantages	Disadvantages
Baiting	
• Insecticide well-targeted at locusts • Little specialist equipment required	• Large quantities of bait required • Arduous mixing process • Slow application • Danger to non-target species
Dusting	
• No specialist equipment necessarily required	• Large quantities of dust required • Slow application • Control may be poor • Hazardous for operator health
Water-based spraying	
• Faster work rate than baits and dusts • Liquid insecticides give more rapid and reliable control than dusts and baits	• Spraying equipment required • Large volumes of water required which may be impossible to find in Desert Locust habitats • Large volumes of spray formulation to be transported and applied • Narrow swath width so work rate is slower than ULV spraying • Evaporation is likely to be a problem in hot, dry conditions
ULV Spraying	
• Very fast work rate • Liquid insecticides give rapid and reliable control • Water is not required • Small volumes of liquid to be transported and applied • No mixing usually necessary	• Specialist spraying equipment required • Equipment must be properly calibrated and maintained • Operator risk from concentrated spray formulations • Cannot spray without wind • Batteries required for hand-held equipment • Spray may drift a long way and it is difficult to 'spot spray' small targets

Advice ULV spraying is considered to be the fastest and most cost-effective way of controlling locusts, provided the correct equipment is available and the control staff are trained in ULV spray techniques.

Practice Some countries such as India and Sudan use dusting extensively, mainly because it can be carried out without specialist equipment or training. There is also some water-based spraying (emulsifiable concentrates) carried out, usually when no ULV formulations are available. Most locust-affected countries have switched or are switching to ULV methods.

Sprayers

There are various types of sprayer in use for locust control. They can be characterised by looking at the method by which they break the insecticide up (atomiser type), the means by which they are carried during spraying (sprayer platform) and the method of dispersal/transport of droplets after atomisation (droplet transport).

Atomiser type

Different types of atomiser produce different types of droplet spectrum - see Box 3 for definitions and terminology. The 3 main types of atomiser used in locust control are:

- Hydraulic nozzles. Liquid is forced under pressure through a small hole and is broken up into droplets as it comes out. Hydraulic nozzles are commonly found on lever-operated knapsack sprayers and on tractor booms. Generally, the droplet spectrum from hydraulic nozzles is not suitable for ULV spraying since the drops are usually large (VMD 200 - 400 µm) and the droplet spectrum is very wide (R is more than 2.5). Higher liquid pressures and smaller nozzles produce smaller droplets.

- Air-shear nozzles. Liquid is released from a pipe into a blast of air which breaks the liquid into droplets. Air-shear nozzles are often used on knapsack mistblowers and on vehicle-mounted ‘cannon’ sprayers. The vehicle-mounted exhaust nozzle sprayer (ENS) has a type of air-shear nozzle with the airblast provided by the exhaust gases from the spray vehicle. It is possible to get smaller droplets (VMD 40 - 200 µm), but the spectrum is still quite wide (R is usually greater than 2) so this type of atomiser is not efficient for ULV spraying. Faster airblasts produce smaller droplets.

- Rotary atomisers. Liquid is fed onto a rotating surface which throws the liquid off it in droplets. The faster the rotation, the smaller the droplets. Some rotary atomisers have spinning discs which produce a very narrow droplet spectrum, especially if they have teeth on their edge (R as low as 1.2). Droplet spectrum from discs is best with a low flow rate, but if a larger flow rate is required, several discs can be stacked one behind the other. Some other rotary atomisers have spinning cages, or spinning cylinders and although their droplet spectrum (R about 1.7) is often not quite as good as spinning discs, they can cope with higher flow rates and can be more robust in the field than discs. Faster rotational speed produces smaller droplets.

Table 3 Summary of advantages and disadvantage of different types of atomiser

Advantages	Disadvantages
Hydraulic nozzles	
• Simple and cheap	• Wide droplet spectrum - no good for ULV • After a prolonged period of use, the nozzle can wear, leading to a further deterioration of the droplet spectrum.
Air-shear nozzles	
• Simple and cheap • Narrower spectrum than hydraulic nozzles	• Power required to produce the airblast • Droplet spectrum still moderately wide
Rotary atomisers	
• Narrow droplet spectrum - suitable for ULV application	• External power source required to spin the atomiser. • Usually more care and maintenance required than other types of nozzle.

Box 3. What is the droplet spectrum

If there is a perfect drop size for a particular locust control situation, then a perfect ULV sprayer would produce droplets all of that size. However, no such field sprayer exists - every sprayer produces a range of droplet sizes called a droplet spectrum. A wide droplet spectrum contains many different droplet sizes and a narrow droplet spectrum contains droplets of approximately the same size. A narrow droplet spectrum is best for ULV spraying.

Droplet spectra are usually described using the values of Volume Median Diameter (VMD) and Number Median Diameter (NMD). These are both types of average used to represent the range of droplet sizes in the spectrum - one based on volume of the droplets, the other on number of droplets. VMD is defined as the diameter of the droplet which has half of the volume of spray in larger droplets and half of the volume in smaller droplets. NMD is the diameter of the droplet which has half of the number of droplets of a larger diameter and half of the number of droplets of a smaller diameter.

The ratio of VMD and NMD values (R) gives a rough measure of the width of the droplet spectrum - the nearer it is to 1, the more similar are the droplet sizes, the larger it is, the greater the range of droplet sizes.

For example if a sprayer has a VMD of 90 µm and an NMD of 60 µm the VMD:NMD ratio is calculated as below:

$$R = \frac{VMD}{NMD} = \frac{90}{60} = 1.5$$

It is thought that the VMD from ULV locust sprayers should be between 50 and 100 µm and that NMD should not be less than half of VMD i.e. R is less than 2.

Another way of describing a good droplet spectrum for ULV locust control is to say that it should have at least 80% of the spray volume in the size range 50 - 100 µm. Some types of atomiser can achieve these two aims and some cannot.

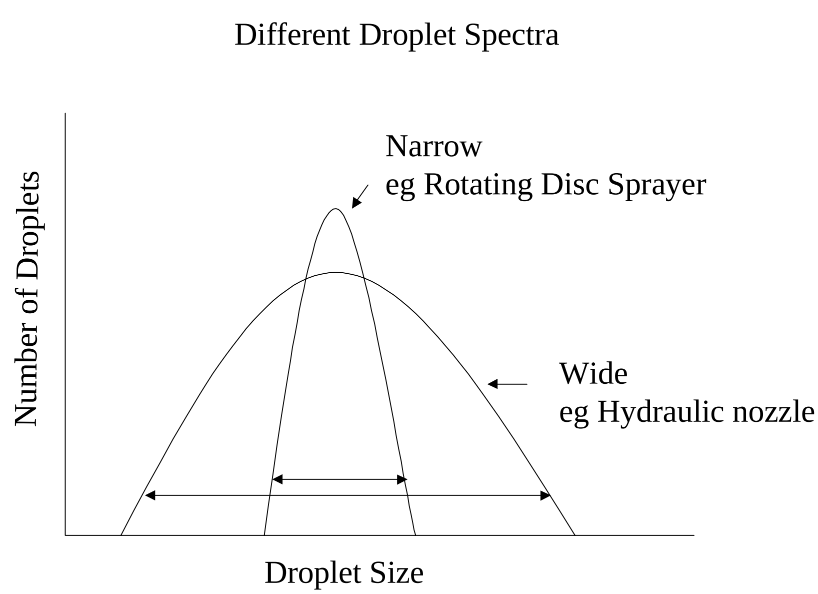

Figure 2 Different Droplet Spectra

Advice

Rotary atomisers are the most efficient type for ULV spraying. Droplets should be of fairly uniform size (R ratio less than 2) and the VMD between 50 and 100μm, although there are no firm data to support these estimates at present, nor to say whether different sizes are significantly more efficient for different locust stages or target configurations. Air shear nozzles are inefficient with insecticide because they produce many large droplets which fall-out very near to the sprayer, and many very tiny droplets which drift out of the target area without impacting. This is not to say that they don't work - they can still be effective against locusts when set-up properly - but they are wasteful of insecticide. The only case where ULV pesticides should be applied through hydraulic nozzles is with aerial spraying (and then only in an emergency), because the air-shear from the forward speed of the aircraft through the air can help to atomise the liquid. In this case nozzles should be angled forward at 45 degrees to get the smallest possible droplet size. Operations will nevertheless be inefficient and more wasteful than with rotary atomisers.

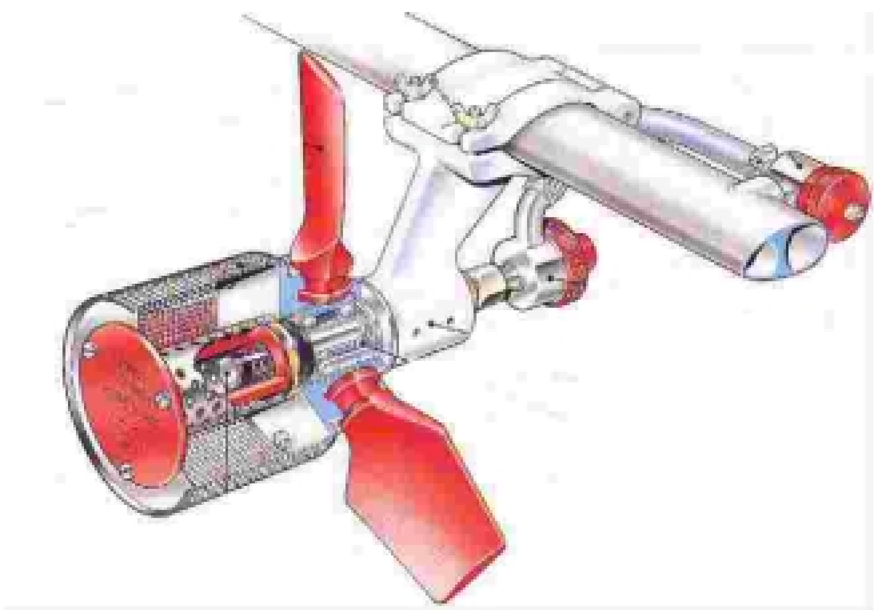

Figure 3 An example of a rotary atomiser - Micronair AU5000 for aircraft

Practice ULV insecticide is still applied in some countries through a variety of non-rotary atomisers including airblast nozzles on vehicle-mounted exhaust nozzle sprayers (ENS), knapsack mistblowers, and vehicle-mounted 'cannon' sprayers, and through conventional hydraulic nozzles on aircraft. In this latter instance, they have been seen facing in all directions including directly backwards, which would produce very large droplets and be very wasteful of ULV pesticide.

During the days of dieldrin, the most commonly used ground spray equipment was the vehicle-mounted exhaust nozzle sprayer (ENS). This was produced originally by a company in UK, but the simple design has been copied with some modifications and improvements in various countries including India, Yemen, Iran and Morocco. Delivery of pesticide to the air shear nozzle, and atomisation there, is powered by the exhaust gas pressure. The main drawbacks to this simple system are the relatively poor droplet spectrum produced, the back pressure on the vehicle exhaust system which can cause damage to the engine and the variable flow rate which depends on vehicle throttle opening - if going uphill or over soft sand, flow rate (which is very high anyway) increases dramatically. Despite its shortcomings, there is massive inertia in this technology - it has proved very difficult to encourage control organisation to switch over to newer ULV sprayers with rotary atomisers. This reluctance is due to the fear that newer sprayers are not robust enough to continue working under the rough conditions found during locust control operations - the ENS may not be very efficient, but it is difficult to break and requires almost no maintenance. It is true that the early vehicle mounted sprayers with rotary atomisers were unreliable, with major breakdowns occurring very quickly in various components such as atomiser drive mechanisms and pump seals. Confidence in this new technology plummeted. However, teething problems have been mostly ironed out now, and users have realised that for these more sophisticated sprayers to be sustainably effective in delivering more safe and efficient locust control, there has to be a re-think on levels of training in their use and levels of workshop support to service and repair them. Currently, rotary atomiser vehicle sprayers are being used more widely, but the bulk of pesticide sprayed from vehicle-mounted sprayers is probably still being applied through ENS-type sprayers.

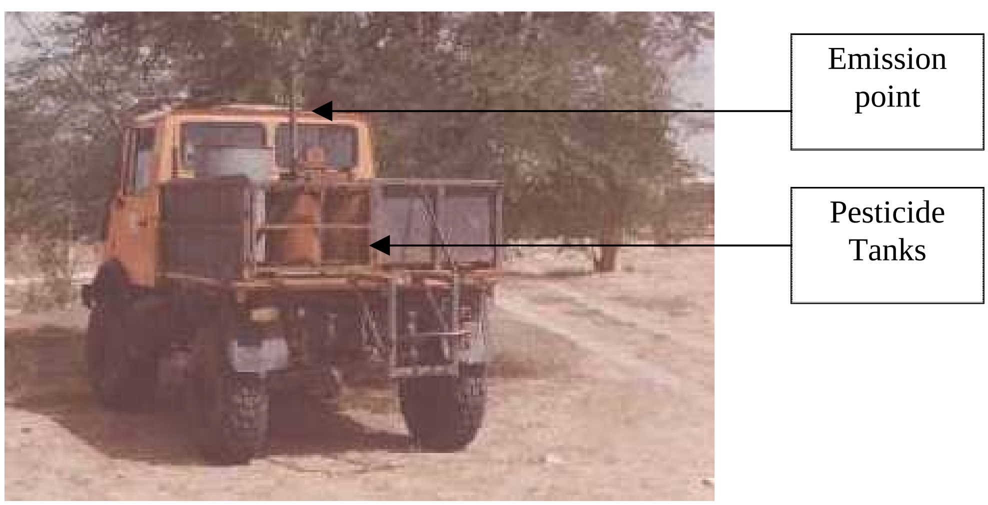

Plate 1 Exhaust Nozzle Sprayer

There is also a certain reluctance to adopt the hand-held spinning disc sprayers in some countries. This is due partly to the initial perception that they are small and flimsy and can't possibly treat large areas effectively, and partly to the fact that walking with a hand-held sprayer is harder work than sitting in the cab of a vehicle-mounted sprayer. This reluctance applies to any portable sprayer, and once staff have experienced how quickly and successfully a team of operators can treat even quite large hopper bands, even over terrain not passable in a vehicle, they have more confidence and motivation to use them.

Platform

Sprayers can be carried by an operator (portable sprayer), mounted on a four wheel drive pick-up truck (vehicle-mounted sprayer) or on an aeroplane, helicopter or microlight (aircraft-mounted sprayer). The principle of use is the same for all of them, only the scale and speed of operation and certain practical limitations are different. Table 4 below compares their performance. In practice during a control campaign, different sprayer platforms are combined, for example a vehicle-mounted sprayer can travel with 3 or 4 hand-held spinning disc sprayers - the vehicle sprayer sprays the larger targets, and portable sprayer operators can dismount to treat small patches and difficult terrain such as soft sand and wet or rocky areas.

Aerial spraying with helicopters is almost the same as with fixed-wing aircraft, since the downdraft of air is the same when they are flying at spraying speed. Helicopters do have some advantages such as the ability to operate without an airstrip, to carry out surveillance and to land for efficacy monitoring after spraying. They can also spray canyons and gorges which would be dangerous from a fixed wing aircraft, but they are much more expensive to operate, and generally have a slower cruising speed and a shorter range.

Table 4 Summary of performance of different sprayer platforms

Performance factor	Portable	Vehicle-mounted	Aircraft-mounted
work rate?	slow (30 ha/day)	medium (250 ha/day)	fast (8000 ha/day)
speed of response?	fast	fast	can be slow
spray in rocks/hills?	yes	no	yes
spray over soft sand?	yes	no	yes
spray single bands?	yes	yes	not efficiently
spray settled swarms?	difficult	difficult	yes
spray flying swarms?	no	no	yes
easy monitoring?	yes	usually yes	no - difficult
insecticide efficient?	any size target	above 1 ha	above 25 ha
involve community?	possible	not much	no
appropriate target size?	up to 10 ha	1 - 100 ha	over 25 ha

Advice The choice of sprayer platform should be made taking into account several factors including target size, urgency of control, trafficability of target area, distance from locust base, etc. Generally speaking, the smallest sprayer consistent with the urgency of control and area infested should be used, since small sprayers are more efficient with pesticide, and are more likely to get it on the target. For example, small bands are best treated with portable sprayers - if vehicle mounted sprayers and especially aircraft-mounted sprayers are used, a substantial quantity of insecticide is likely to deposit away from such a small target.

Practice Although data are scarce due to little detailed monitoring and reporting, it seems that in most countries, by far the greatest effort in terms of staff time goes into spraying with vehicle-mounted sprayers. For any medium or large scale campaign, aerial spraying is mobilised when infestations are getting out of control and, as a result, usually accounts for a larger treated area (and quantity of insecticide applied) than all other modes of application put together. Portable sprayers and dusters are sometimes used, but the full potential of hand-held spinning discs to complement vehicle mounted hopper band spraying is not currently exploited.

Droplet transport

Some types of sprayer have ‘air-assistance’ i.e. an airblast carries the droplets for a distance after atomisation e.g. knapsack mistblower or vehicle-mounted airblast sprayers. These contrast with sprayers which simply release the droplets into the influence of the cross wind - called passive drift sprayers. It is important to remember that these artificial airblasts do not reach more than a few metres and it is a misconception to think that they are a substitute for a steady windspeed in carrying the droplets across the swath. After a few metres being carried by the airblast, the droplets are released to drift with the wind as in a passive drift sprayer. This misconception, together with a scepticism about quieter sprayers whose ULV spray is difficult to see, has probably led to the popularity of large canon-type sprayers in West Africa. In their favour, airblast sprayers can be useful for throwing the spray up to a greater initial height from where it will be carried over a greater downwind distance in light winds and for reaching locusts roosting in the tops of medium-sized bushes or on the downwind side of dense vegetation. It takes a lot of energy to produce an airblast and a separate engine is required to produce it, which in turn requires fuel, oil and maintenance.

Table 5 Advantages and disadvantages of airblast and passive drift sprayers

Advantages	Disadvantages
Passive drift	
• Low energy requirement • Simple	• Droplets are not given an initial dispersal by the airblast
Airblast	
• Can be directed upwards or cross wind	• High energy requirements and greater maintenance/servicing requirements

Plate 2 Airblast Sprayer

Advice Airblast sprayers are more expensive initially, are more complex pieces of machinery requiring a higher level of servicing and repair, and require fuel and oil to run. Many canon-type sprayers are designed for high volume spraying of very dilute formulations and are not safe for locust spraying. Hoses are not resistant to ULV formulations and some sprayers require an operator to be on the back of the vehicle to switch it on and off. ULV knapsack mistblowers pose additional risks to the operator due to the concentrated pesticide being carried close to his back (the tank or pipes may leak), and if care is not taken with pointing the airblast downwind or at least cross wind, spray can be blown back onto him. Ear defenders should also be worn. If it is felt that these disadvantages can be managed, the advantages of wider track spacing and access to locusts in dense vegetation, in taller bushes or on their downwind side may justify their use.

Practice The misconception about the usefulness of an airblast is widespread. It is often claimed that they can operate in zero wind conditions because they produce their own wind. Impressive claims are also made of the height of trees the airblast can reach, but these estimates are with the sprayer stationery. In practice, when an airblast sprayer is moving along at its forward speed, there is no time for the airblast to entrain a column of surrounding air and the result is that the ‘throw’ of insecticide is rarely more than 3 or 4 metres. When airblast sprayers are used to reach locusts high up in or on the downwind side of bushes, the concept of ‘dose’ i.e. quantity of active ingredient per hectare, is no longer applicable. By directing the airblast at a particular spot for seconds at a time, rather than moving along at the sprayers normal forward speed, the operator applies a vast overdose. This may be justified if there really is no other way to reach the locusts and control is not occurring in an ecologically sensitive area.

CHAPTER 2. PRACTICES AND METHODS

Target type and spray strategy

There are several different types of ULV spray strategy used to deal with the different types of locust target. In practice, two or more of these are often combined in a campaign. They are usually *full coverage* techniques i.e. the whole target area is sprayed. In some strategies, however, only part of the area is sprayed - see barrier spraying below.

Spraying single bands

This involves finding and spraying individual hopper bands. Portable or vehicle-mounted sprayers can be used, but if aircraft are used, a lot of insecticide will be wasted since they cannot help but spray an area much larger than a band. Aircraft are not pesticide-efficient for targets less than 0.25 km^2. The difficulty with spraying individual bands is finding a sufficient proportion of the total population to have an impact on the size and number of the resulting swarms flying out of the area. In any medium or large infestation, unless a very large number of vehicles and staff are available, the proportion of hopper bands found and controlled will be small. Of course the perception is somewhat different - all of the hopper bands found are treated, but it is the ones which are not found which are the problem.

Plate 3 A small hopper band

Spraying blocks of bands

This involves marking a block of land which has a relatively high proportion of its surface area covered by bands, say 5%. The whole block is then sprayed by vehicle or aircraft. This is very wasteful of insecticide but may be the only method fast enough to treat an area containing many bands before they fledge.

Barrier spraying to control bands

This means spraying a persistent insecticide onto widely spaced strips of vegetation in areas infested with hopper bands. As the bands move around, they eventually encounter these strips and eat the sprayed vegetation. Barriers can be sprayed with portable, vehicle-mounted or aerial equipment. Research is also being conducted on the efficacy of spraying vegetation in lattices or grids.

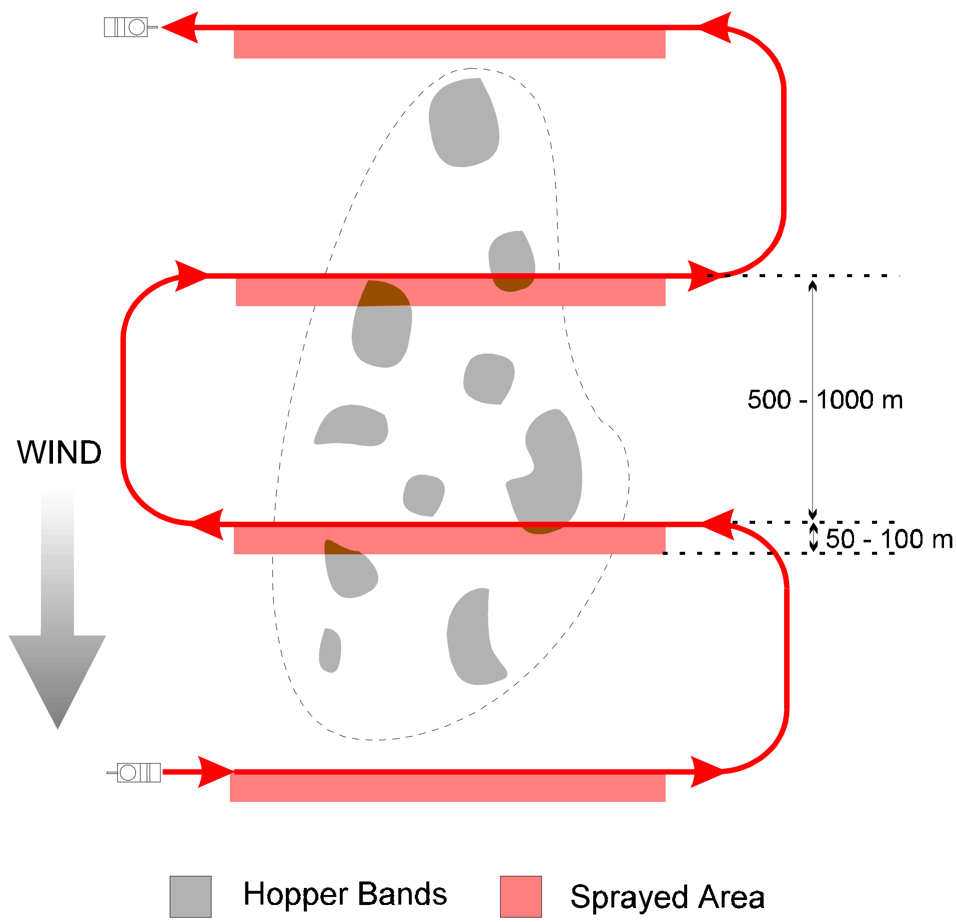

Figure 4 Idealised barrier treatment

Spraying settled swarms

This means spraying swarms which are roosting on vegetation, usually either in the morning before take-off or in the late afternoon when the swarm has settled again. Settled swarms are usually sprayed by aircraft but vehicle-mounted airblast sprayers are sometimes used, occasionally at night. Sometimes the swarm roosts in vegetation too high to reach with ground sprayers and aerial spraying is then the only appropriate method. The advantage of spraying swarms is that there are many millions of locusts gathered in one place - they are composed of locusts from many bands or smaller swarmlets so the problem of finding many individual targets is reduced. Swarms are also sometimes sprayed while laying eggs, although they usually disperse before laying and are not such a dense target.

Plate 4 Roosting locusts

Spraying flying swarms

Swarms are sprayed from aircraft while they either milling (some of them making short flights around the roost site) or in full flight.

The advantage of spraying flying swarms is that flying locusts collect droplets efficiently since they are moving quickly (about 3 m/s) and their wings are beating even faster, collecting droplets efficiently from the air.

The flying swarms may be milling around the roost site or they may be in full flight either as stratiform swarms i.e. low flying up to heights of 100 m or cumuliform swarms i.e. flying up to heights of 1000 m or more. Swarms are usually stratiform in the morning and late afternoon, and become cumuliform in the heat of the day when convection is taking place from hot ground. These flight patterns are not completely separate and swarms may take a form halfway between stratiform and cumuliform.

Table 6 Advantage and disadvantages or different types of locust target tactics

Advantages	Disadvantages
Spraying individual bands	
• Can be carried out by ground spray teams • Efficient with pesticide since it is only directed at bands	• The difficulty of finding a significant proportion of bands
Spraying blocks of bands	
• No need to find and mark individual bands • Large areas can be treated by aircraft	• Very inefficient with pesticide since most of the area sprayed is not infested
Barrier spraying	
• No need to find and mark individual bands • Timing is not critical since products are persistent • Efficient with pesticide and relatively environmentally friendly since most of the infested area is unsprayed	• Results are not immediate since bands may take some time to encounter a barrier • Feedback on efficacy is minimal since bands will die (or not) unseen; they may also join with other bands which have not encountered a treated barrier.
Spraying settled swarms	
• Many locusts gathered together in a discrete, dense target	• Small spray window in daylight (after landing and before taking off) • Locusts may be so densely packed as to shield each other from spray
Spraying flying swarms	
• Easy to spot from a distance • Many locusts gathered in one target • Flying locusts collect droplets efficiently	• Without locust-proofed aircraft, flying near swarms is a hazard • Flying swarms may be very dispersed • No real validated advice available on technique

Advice Specific advice on target type and strategy is difficult due to the many factors to be considered in different circumstances. An appreciation of the ‘selective perception’ problem - controlling bands which are found, but failing to locate the majority - can help campaign managers to allocate band control resources more effectively and to make contingency plans for forthcoming swarm control. Similarly, an appreciation of the logistical (not to mention economic and environmental) advantages of barrier spraying might have a beneficial influence on choice of insecticide product. If there are large numbers of late instar hopper bands over large areas, spraying blocks of bands might be the only method fast enough to prevent swarms escaping the area. Spraying flying swarms is potentially very efficient, but is more likely to be achievable with stratiform swarms and should only be carried out in aircraft fitted with mechanisms to stop the locusts blocking air vents, cooling fins and visibility through the windscreen.

Practice Choices are rarely made as to which stage of locusts to control. It would be a very controversial political decision to ignore hopper bands on the basis that they will provide a better spray target once they fledge and group together into a swarm. In practice, locust control organisations control whatever stage of locusts is present - if band control fails then the resulting swarms are attacked.

Barrier spraying has not been in the armoury of campaign managers for a decade or so, and this has doubtless affected the efficacy of hopper band control operations. This was one of the reasons behind the huge blocks of bands sprayed in West Africa during the late 1980s - in the absence of barrier technology, there was no other practical way to reach them all in time. However, new barrier products are becoming available with doses validated by the FAO Pesticide Referee Group, and barrier spraying is beginning to be used again.

Spraying of settled swarms is frequently carried out, usually by air, but sometimes using ground-based equipment. Spraying of flying swarms is rarer, due to the shortage of locust-proofed aircraft and experienced pilots. Some people claim that the different meteorological conditions in West Africa (as compared with East Africa) mean that flying swarms rarely present a dense enough target to spray.

Finding and delimiting individual targets - bands and swarms

The mechanism for finding locust targets varies from country to country - see the FAO Desert Locust Survey Guidelines. Typically, if the survey teams have identified an area infested with bands, or there are reports from the local community of locusts in an area, the control teams in vehicles will go to that area in order to spray and/or direct the spray aircraft. If the locusts are very far from the locust base or are in very difficult terrain such as mountains, then a spray aircraft might go there on its own without ground support.

Searching for individual bands or settled swarms can be carried out by driving through the infested area in a systematic way looking for vegetation, locusts and for signs such as birds feeding on them. Information from inhabitants or nomads is extremely useful in locating targets. An aircraft is also very useful for locating swarms because of its high vantage point and speed. Hopper bands are sometimes difficult to see from the air although a helicopter can more easily fly lower and slower and if a possible band is spotted, can turn back for a closer look and land if necessary.

How effective band search activities are will depend on the area each team has to cover. In most cases each team has to search a far larger area than would be possible if a complete 'sweep technique' were used i.e. driving backwards and forwards following a grid pattern using a spacing which allows all the land area to be seen by eye. In any case the terrain may not allow this due to soft sand, crops, rocky outcrops, wadis etc. Field staff often say that they know the sort of areas where hopper bands are usually found and narrow down their search to these areas. There is no evidence as to how much this local knowledge improves the search success. What is clear is that a great job may be done of controlling the targets which are encountered , but the control will be futile if a significant proportion of the targets remain undiscovered.

When a band or swarm is located, the search team either marks the location of the target for control teams/aircraft which will arrive later, or if it is equipped with spraying equipment it carries out the control itself immediately. If the target is to be marked for later control, flags can be used, or better still, the map coordinates (latitude and longitude) can be recorded with a hand-held Global Positioning System (GPS) unit if they are available. These coordinates can then be given to ground spray teams also equipped with GPS, or relayed to spray aircraft pilots (if there is radio communication) to guide them to the targets.

Aircraft sometimes fly search and spray sorties during which they fly around the infested area spraying any locust targets they spot from the air. Accountability with this sort of operating strategy is minimal.

Delimiting and marking individual discrete targets - bands and swarms

Before spraying starts on large bands (more than 0.5 ha) or swarms, the control team should *delimit the target*. This means determining how big the target is and where its boundaries are.

Advice This can be done by driving or walking around it and if possible, placing flags, people or vehicles at the four corners of a spray area which is big enough to cover the target. If the target is large (more than 1km^2) and it is planned to spray it by aircraft, GPS co-ordinates can be recorded for the four corners for relaying to the pilot and smoky fires can be lit at each point. The smoke also helps the pilot to judge the wind direction. The spray area should extend a few metres beyond the edges of bands to be sure of covering them. If a band is moving, the spray area should be extended even further (20 - 40 m) in the direction of movement so that locusts move into (and hopefully feed on) sprayed vegetation.

Practice Delimitation and marking are rarely carried out in practice. Experienced teams can spray small targets quite accurately without delimiting and marking, but larger targets are more difficult. In some instances, where the target extends beyond the line of sight, ground spray teams simply start spraying on the 'baseline' of the spray block i.e. the downwind edge, then continue spraying (moving upwind at the end of each spray pass) until they have covered the locust target. Both these techniques apply to aircraft too - a small swarm can be seen in its entirety from an aircraft and the pilot can easily determine where to start and stop spraying. With a larger swarm, if the ground party can mark out the baseline, the pilot can spray that, determine the spray track compass bearings then continue with spray passes, moving upwind between each, until he has completed spraying the swarm.

Delimiting a block of bands or a large scattered swarm

If there is a large area with bands scattered through it, or a swarm which is scattered in patches over a large area, it is also important to determine the extent of these targets in order to guide barrier spray applications or aerial spraying. However, the difficulties of delimitation are even greater than with discrete targets. There is not usually time to carry out an accurate sweep from a vehicle to find and plot the position of all of the locust targets, so a rough and ready technique has to be used to get a reasonable idea of the boundaries of the infestation.

Advice A transect can be driven through the suspected infested area in one direction to find out where the infestation starts and ends. The vehicle then goes to the middle of this line and drives a second transect across the block at 90 degrees to the first one to see how far the block extends to either side. These then form a cross in the middle of a rectangular block. The vehicle then drives around the edge of the block to mark the corners, and its size is adjusted if necessary to include locusts which are outside the original rectangle. Some locusts will often still lie outside such a block, but this method is preferable to wasting insecticide by spraying a much bigger area which is possibly infested at a very low level.

If the area of bands or swarms is very large indeed, a more systematic method is necessary to demarcate the spray block. Drive a search pattern through the suspected infested area. Spacing between the lines will depend on whether the targets are swarms or bands. It should be possible to spot settled swarms or scattered patches of adults at a distance of around 100 m to either side so a spacing of around 200 m can be used. Bands are difficult to see at more than 50 m distance so a spacing of around 100 m should be used. Since there will be no markers to guide the vehicle, drive on a compass bearing, then for the opposite direction, drive at 180 degrees to the original line. A GPS can be used to navigate instead of a compass and is also very useful eventually for marking the corners of the large spray block.

Both of these methods are hard to validate quantitatively, but large errors are likely and their efficacy depends on judgement, guesswork and luck.

Practice Again delimitation is probably rarely carried out in a systematic way on large blocks with scattered targets and if it is, little is documented on techniques used, efficacy or efficiency. Spraying such blocks is usually done by air, and responsibility for determining the boundaries of the spray block is often delegated to the pilot, so validation is very difficult.

Spraying techniques - ground targets

These include individual bands, blocks of bands and settled swarms. Ground spray teams vary in their composition from a minimum of a driver with his vehicle mounted sprayer, to teams of 6 or 7 including a graduate Locust Officer, a mechanic, casual labourers and sometimes a cook if the team is camping far from habitation. There is usually an additional vehicle in which tents, bedding, foodstuffs, water etc. can be carried, but sometimes these have to be carried on the same vehicle as the sprayer and the pesticide drums. However many people there are in the team, the responsibility for spraying is frequently delegated to the driver who may not be literate or trained in modern locust control techniques. This is a staffing management problem which needs to be addressed before spraying performance can be improved on a large scale.

Calibration

Whichever ULV sprayer, platform and insecticide have been chosen, calibration is required i.e. the measurement and adjustment of various parts of the sprayer in order to apply the correct amount of insecticide, in the right size spray droplets, to the right place. If calibration is not carried out, spraying may be ineffective or insecticide may be wasted.

Advice

Three things need to be calibrated to achieve an efficient result:

- droplet size - current recommendation is a VMD of 50 - 100 µm to ensure that the droplets will spread and deposit well over the target area and deposit reasonably well on locusts and/or vegetation. Since measuring droplet size requires special equipment and training, in practice, the atomiser must be set to produce a rotational speed which will produce an assumed droplet size according to the manufacturer's handbook. The droplet size may have to be adjusted for different spraying situations.
- emission height - the height at which the cloud of spray droplets is emitted will influence where the wind carries the drops, so if height is adjustable, it must be set so that insecticide is well distributed over the target area. In general, the higher the emission height, the wider the swath, but if the emission height is too high, there is a risk that the droplets will not come down in the target area. If the wind is very strong the height should be reduced. Depending on the wind speed, emission height for hand-held sprayers should be 0.5 - 2 m, for vehicle-mounted sprayers 2- 3.5 m (although most are not adjustable) and for aircraft 5 - 10 m although this will have to be higher for milling/flying swarms. Radio communication is very useful for the ground staff to tell the pilot to fly lower or higher according to the wind conditions

on the ground. Airblast sprayers can be angled up or down to alter the effective emission height (up to around 8m).

- recommended dosage of insecticide - the dosage is the quantity of *active ingredient* applied to an area of land, usually expressed in units of grammes of active ingredient per hectare (g a.i./ha). The recommended dosage is the amount known to be sufficient to kill the locusts reliably without wasting pesticide The FAO recommendations for the doages for various products are given in the FAO Desert Control Guidelines; updated recommendations are given in the Reports of the Pesticide Referee Group as new information becomes available.. If there is no recommendation from FAO for a particular product dosage, the manufacturer may recommend a dosage or organisations can carry out their own field trials.

Practice There is generally very little appreciation of the importance of droplet size, nor attention paid to adjusting it. Hand-held spinning disc sprayers are sometimes operated when the batteries are nearly exhausted, resulting in very large droplets. Few drivers, vehicle-mounted sprayer mechanics or aircraft engineers understand how to, or when to, adjust droplet size on their rotary atomisers and manufacturers handbooks, especially in the local language, are rarely available. Even the ENS nozzle is frequently badly adjusted, producing very large droplets which are even less efficient than normal.

Trained staff adjust emission height to compensate for different windspeeds - in low winds, spinning disc sprayers can be held higher and aircraft can fly higher. Passive drift vehicle sprayers usually have no height adjustment, but airblast vehicle sprayers have the capacity to set the airblast at different angles, although this method of compensating for higher or lower winds is rarely used. There are sometimes problems with achieving the correct flying height during aerial spraying. Some agricultural pilots are used to touching their wheels on the crop and tend to fly too low, and some pilots with little or no agricultural experience are not comfortable at low altitudes and fly too high, especially if there are trees in the target area. The former will mean that spray is not carried over a wide enough swath and the latter will mean loss of spray out of the target area as drift.

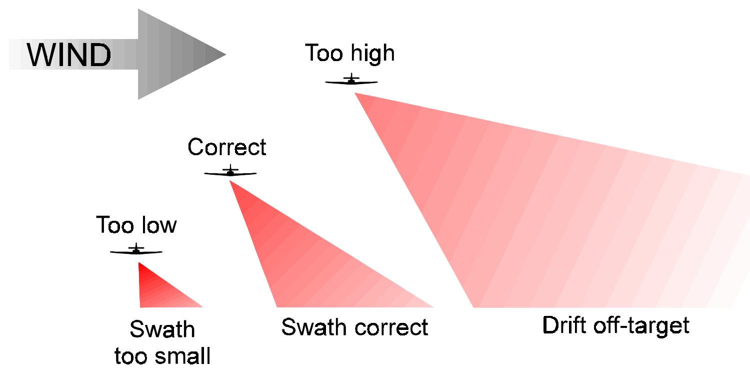

Figure 5 Effect of release height on spray deposit

In order to achieve the correct volume application rate and therefore the recommended dose, 3 spray parameters have to be regulated: forward speed, track spacing and flow rate. Forward speed (whether walking, driving or flying) is usually difficult to alter substantially, and track spacing is determined by the wind conditions and/or traditional practice, so flow rate is the most convenient parameter to regulate. The culture of the ENS still pervades most ground control operations, i.e. it was not usually possible to adjust the flow rate on the ENS (and it was so variable in the field anyway) so what was the point in measuring it in the first place?

Even if trained in calibration techniques, most operators do not have access to measuring cylinders/jugs, distance measures, or the stop watches required. It appears that most of the time, spray equipment is used as it is found, at a speed which is comfortable and using an 'eyeballed' track spacing which seems about right. In some instances flow rates are turned up to the maximum to give the operator more confidence that something is coming out of the sprayer and is likely to have an effect on the locusts. Due to the difficulty of seeing where ULV spray is going, track spacings are often cut down to distances which give the driver more confidence that he is covering the area properly, also leading to heavy overdosing.

These practices apply as often for aerial spraying as for ground spraying - especially if the aircraft crew are more used to high volume crop spraying - and due to the scale of such operations, can have much wider implications in terms of control efficacy, economics of operations and environmental impact. The pilot and engineer are usually treated with great respect and their word is rarely questioned - sprayer settings and flow rates are not often checked by ground staff.

In some countries the legacy of the ENS lingers in the form of a sort of barrier spraying with organophosphate insecticides - operators report using the ENS to spray fenitrothion at track spacings of 300 m or more. Even with the high flow rate of the ENS, this will result in strips of sprayed vegetation and an overall underdose over the whole area. It is reported to be effective against hopper bands and it is conceivable that although the fenitrothion has a half life of a day or two in the field, the hopper bands are mobile enough to encounter one or more barriers while the product is still biologically active.

Regard for meteorological conditions

Advice Ideally, locust control spraying should only be carried out in dry conditions, spraying in a cross-wind direction in a good steady breeze, before (or after) the sun is very high in the sky. Spraying should stop if rain is imminent, the wind dies or strong convection is occurring - characterised by frequent changes in wind direction and strength.

Practice The extent to which these meteorological factors are taken into account varies from country to country, but is generally only partial at best. Wind direction is often found by throwing up dust or vegetation and watching which way it is carried, but wind speed and thermal stability are rarely monitored due to lack of equipment and/or knowledge of what the effective limits are. Some countries have upper wind speed limits which are quite low and are probably based on advice for high volume crop spraying (where often the need is to avoid spray drift, particularly with herbicide application). Spraying usually continues until the targets in the vicinity have been treated or the conditions are too hot for the staff, rather than because of the onset of strong convection which might carry the spray upwards.

Track marking

ULV spraying is relatively forgiving of random errors in track spacings due to the fact that each spray swath overlaps 2 or 3 others. Any consistent underestimate or overestimate of track spacing leads to overdoses and underdoses respectively.

Advice Some method of guiding the operator reasonably accurately to the ends of the spray tracks is desirable especially on larger spray blocks with few landmarks. For portable sprayers, one extra person at each edge of the spray block can stand and indicate where the sprayer should be heading, and then pace out the track spacing distance to the beginning of the next pass. Obviously the sprayer operator can pace out his own track spacing on the side he is actually on, but the difficulty arises with him knowing what direction to set off in when he begins spraying back across the block if there is no marker person in the distance. If a vehicle is being used, these marker staff should have flags - in any sort of undulating terrain, the people themselves can be out of sight to the vehicle for periods of time. For aerial spraying, marking can be done with large flags on long poles, with signalling mirrors or with vehicles.

Measuring the track spacing can be done by counting paces provided the flagman has previously calibrated his pace. The odometer in a vehicle can also be used to measure track spacings.

Practice Track marking systems are rarely used for ground based spraying. The driver of a vehicle sprayer and the operators of portable equipment usually judge their spray directions and track spacings by eye. As has been mentioned, some error is acceptable, but there are frequent errors involving the person or vehicle becoming disorientated after turning at the end of the spray run and setting off in completely the wrong direction.

The presence of flagmen for aerial spraying is more common, but many operations are carried out without them. Aerial spray operations often take place in remote areas and if the target is a settled swarm, the urgency to spray them before they fly away usually rules out the delay of waiting for a ground marker party to arrive. Ability to estimate track spacings varies with the pilot and his level of experience. The onboard compass means that large errors of direction are less likely than with ground spraying, but if long spray runs are being made on large blocks, even a few degrees error on a bearing can mean double dosing of some areas and some areas missed altogether. Differential GPS track guidance systems are available but few locust spray aircraft are equipped with this modern equipment to date. DGPS has a spatial accuracy of around 1m.

As has been mentioned, smoky fires are sometimes lit at the downwind corners of the spray block. These serve the dual purpose of marking the ends of the first spray run and giving a clear indication of wind direction.

Other aspects of spraying ground targets

- Emission height, as has been mentioned, this factor is often not adjusted for different spraying conditions, and during aerial spraying, some inexperienced ULV spray pilots fly too high and some fly too low.
- Communications - ground spray teams and marker parties usually have HF radio contact with their regional locust base or Headquarters and this can be used for long distance communication with aircraft. Clarity diminishes as the distance between ground party and aircraft decreases. Ideally communication then switches to UHF or VHF bands, but ground parties rarely have the necessary walkie talkies - communication with aircraft often relies on flag signals and guesswork.
- Formation spraying - when two or more ULV sprayers are operating simultaneously on the same block, they must adopt a staggered formation to ensure that they do not contaminate each other. This is sometimes done with hand-help spinning disc sprayers, and occasionally

with vehicle and aircraft sprayers too. It is usually sufficient to have one flag marker on each side of the block to guide the lead sprayer and the other sprayer operators can estimate their position from him. This technique seems to work well where it is used.

- Barrier spraying - this technique is coming back into use with new products such as IGRs and Fipronil. But best practice has not yet been worked out for different products, instars, vegetation types, weather conditions etc. In the days of barrier spraying with dieldrin, it seems that an exact technique was not essential. Since the product was very persistent on vegetation and was cumulative in the insect, it did not much matter whether the aircraft flew at the correct height and applied discrete barriers, or flew too high and produced a low dose over the whole area. Nor did it matter if barrier spacings varied since the highly mobile hoppers were still likely to encounter a persistently biologically active barrier before fledging. Efficacy of the newer barrier products is likely to be more dependent on accurate application and further research is required on optimal parameters. If barriers are going to be spaced at 1km and above, it will be almost impossible for marker parties in vehicles to move between one barrier and the next by the time the aircraft has made its turn, which means that GPS guidance systems will have to be used
- Protective clothing - all sprayer operators should wear nitrile rubber gloves, full length cotton clothing or coverall, boots or shoes and socks to cover the feet and ankles. In addition to these garments, mixers and loaders should wear plastic aprons, goggles or face shield, hat and dust mask (which should be changed frequently). In practice - few personnel involved with locust spraying operations wear the full protective clothing - it is either not available or is not worn by choice. If it is available, it may not be worn because it is uncomfortable under hot conditions, but in addition, among some staff there is a complacency, and sometimes even a bravado, about handling dangerous insecticides.

Improved Application with Differential GPS

Trials undertaken by the project have demonstrated the potential improvements that DGPS can offer to Desert Locust control.

The two following figures illustrate the improvement when using DGPS in simulated spraying trials. The first is a spray sortie without DPGS (but using the recording facilities to plot the position of the aircraft at all times). The second shows a complex flight scenario, with a central exclusion zone, but flown by the pilot with reference to the DGPS system.

It is clear from these results of the hugely improved track spacing accuracy with this equipment. Even allowing for the initial cost of the system, it would pay for itself in a little as 12000 ha of spraying as a result of better application.

The full report of these trials is published as Desert Locust Technical Series Number 29.

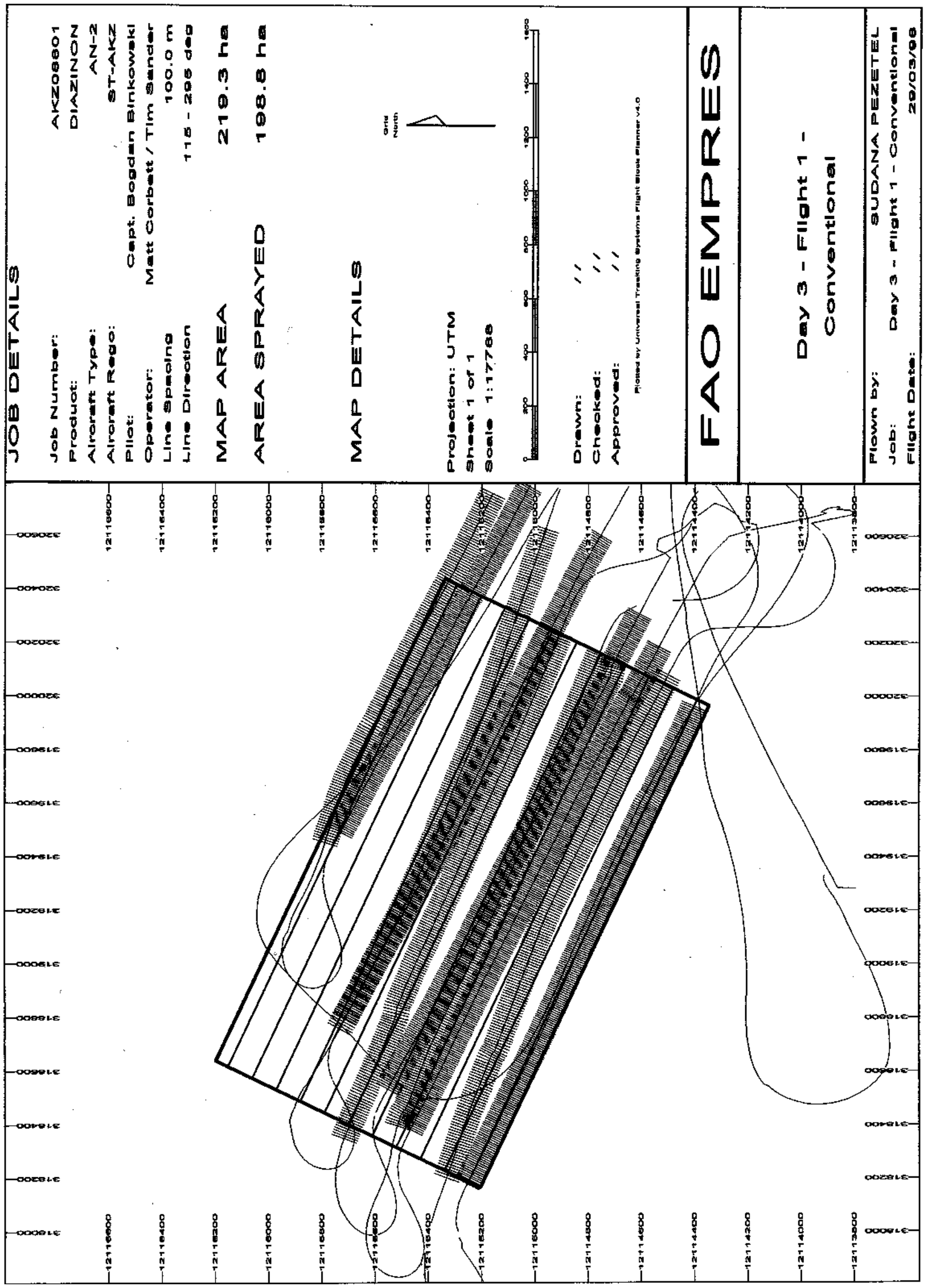

Figure 6 Aircraft spraying – without reference to DGPS

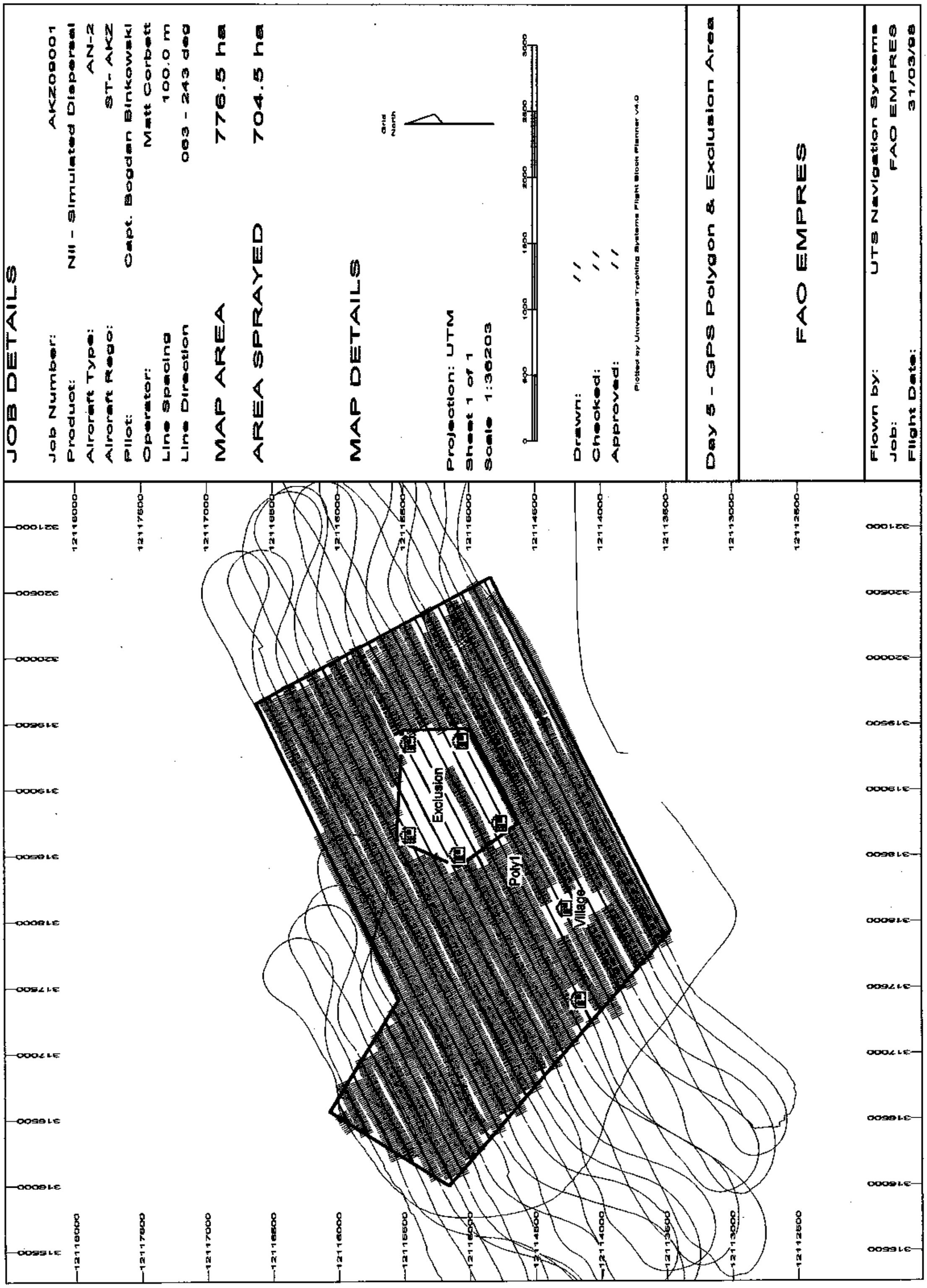

Figure 7 Sortie flown with DGPS

Spraying techniques - flying targets

As with spraying settled swarms, such spraying is potentially highly efficient since millions of locusts, which originated in hundreds or thousands of scattered hopper bands, are gathered together in one swarm target. In addition, the flying insects also collect small falling droplets very efficiently due to their forward speed and rapidly flapping wings. The success of the technique depends entirely on the skill and judgement of the pilot since ground marker parties can be of little assistance with such a mobile target.

Advice ***Spraying milling swarms***

Spraying milling swarms as they are settling in the late afternoon or as they are making short flights before departure in the morning, is an efficient and effective technique. Afternoon spraying may be more effective since the settling locusts will rest on and feed on the contaminated vegetation during the night and following morning. The locusts in milling swarms are often much more densely gathered than those in flying swarms.

As with settled swarms, better control should, in theory, be obtained by spraying the swarm twice using half the flow rate for hopper band treatment to allow locusts to change positions between runs and reduce the number which are shielded by other locusts or vegetation.

Practice The advice given has not been validated and it is not known whether it has even been tried.

Advice ***Spraying swarms in full flight (air to air spraying)***

The aim when spraying flying swarms should be to keep the spray within the swarm for as long as possible. Swarms usually move downwind, but at less than the wind speed so it is no use spraying at the front of the swarm since the spray cloud will move ahead of the swarm.It is much easier to spray low flying stratiform swarms than high flying cumuliform swarms, but there is very little information on either.

Spraying stratiform swarms

The aerial spraying technique is almost the same as that for milling swarms, but with a greater emission height. The aim is to produce droplets which will fall slowly through the swarm so that they can be collected by the flying insects. Many locusts in stratiform swarms may be settled, so a droplet which is large enough to reach the ground eventually is also desirable. Droplets in the 50-100 µm range are a reasonable compromise between these conflicting requirements. As with swarms at the roost site, spraying twice at half the standard flow rate (to give the correct total recommended dose) should in theory achieve better control. The spraying will start at the downwind edge , but if the swarm is moving fast with the wind, the aircraft should reduce its normal track spacing to allow for the swarm moving downwind as the aircraft moves upwind. The accuracy of this will depend very much on the pilot because flag marking will not be possible from the ground.

Spraying cumuliform swarms:
The concept of dose does not really apply to spraying cumuliform swarms - it is more like a space spray than a surface spray. The current advice is to spray repeatedly just above the densest part of the swarm and towards the rear using half the flow rate for settled locust treatment. Spray should remain within the swarm for a long time and the movement of the locusts should bring them into the spray cloud. Spraying should continue until the swarm disappears.

The same sized droplets as used for treating stratiform swarms is suggested, since even a 100 µm droplet will take about an hour to reach the ground from 1,000 m in still air. As cumuliform swarms will be associated with convective updrafts, droplets may take much longer to reach the ground.

With a moderately fast-acting insecticide, such as bendiocarb or chlorpyriphos, lethally dosed locusts should fall to the ground within about half-an-hour, and all those that fall should die. Synthetic pyrethroids may not be suitable because of the problem of knockdown before they have collected a *lethal* dose i.e. sufficient insecticide to kill them - they may recover and fly off later. This has not been confirmed by field observation or trials.

Practice

Confident advice on techniques of air-to-air spraying is even more difficult than for any other forms of locust spraying. There is little documented information about spraying flying swarms, either from trials or actual control operations, and it is not expected that there will be in the near future. Large scale trials are unlikely on swarms since a feature of testing a technique is that it may not be effective - this is a risk many control organisation would not be prepared to take. Observation of current practice from the air is difficult since many spray aircraft are single seat planes. The only information currently available is anecdotal evidence from the pilots which is often difficult to interpret.

However it is still being carried out in some countries. Although it is practised less frequently than in former years due to the small number of 'locust-proofed' aircraft now in service and of pilots with sufficient experience, it was used extensively in Eritrea in 1994 where it was reported that it would have been difficult to control the locusts any other way. Hopper bands developed undetected in remote areas and swarms flew into steep ravines to roost at night. The only time they presented themselves as a good target was when they flew out of the mountainous areas during the daytime. According to descriptions by pilots from DLCO-EA, they spray repeated passes upwind of the densest part of the swarm.

CHAPTER 3. MONITORING CONTROL OPERATIONS

Monitoring is very important in any control campaign. The benefits include:

- information allowing proper accounting for time and resources used
- real-time feedback on progress, success and failure of operations
- identification of problems and constraints which need solving in future campaigns

Advice It is recommended that the following factors are monitored and recorded for every control operation - see Annex 2 for the spray monitoring form taken from the Control Guidelines.

Factors to monitor	Reason why
Identity of monitoring personnel and control team	Accountability for expensive/dangerous resources
Location and size of target	Plotting populations and managing resources
Locust details - age, phase, maturity, behaviour	Important information for tracking progress of outbreak/upsurge/plague
Vegetation - density, greenness, trends	Likelihood of survival/breeding
Insecticide and quantities used	Campaign records and feedback on efficiency and environmental impact
Weather conditions	To encourage awareness and as a record in case of control failure
Application details - equipment, settings, techniques	To encourage application care and as a record in case of control failure
Control efficacy	Quality assurance
Operator safety	Staff health
Environmental impact	Concern for environment and can help reduce future impacts

Other than control efficacy which will be dealt with in the next section, two of the most important factors in determining the efficiency (and likely environmental consequences) of control operations are the size of the target/spray area and the volume of insecticide used. From these two factors the applied dose in g a.i./ha can be calculated. Unfortunately, they are not easy to monitor in the heat of a control campaign and often need to be estimated rather than measured. For example, it may be easy to measure the area of a discrete hopper band by pacing out its dimensions, but larger targets with scattered concentrations of insects or scattered or mobile swarms are more difficult. The recommended technique is to drive a transect through the suspected infested area in one direction to find out where the infestation starts and ends. The vehicle then goes to the middle of this line and drives a second transect across the block at 90 degrees to the first one to see how far the block extends to either side. These then form a cross in the middle of a rectangular block. This assumes that the target is rectangular which it is often not, and in common with the problems of demarcating targets, some locusts will always lie outside the designated target area. Moreover, if the target is very large, this technique will be too time-consuming to be practical and a similar (but probably even less accurate) method with aircraft will have to be used to estimate target size.

The quantities of insecticide used are also difficult to measure e.g. if an aircraft (or vehicle) is spraying several targets with one tank load, it is difficult to measure exactly how much insecticide was applied to each. Estimates have to be made based on flow rate and duration of spraying. One additional advantage that DGPS can offer, if coupled with an appropriate flowmeter, is the ability to record the areas treated, together with the amount of product actually applied.

Practice In reality, very few of these factors are monitored in any systematic way. Very often, information is confined to locust stage and phase, total area treated over a particular period and volume of insecticide used. And to make matters worse, the area treated is usually a theoretical figure calculated by dividing the volume of insecticide used by the Volume Application Rate (VAR). e.g. if 150 litres of bendiocarb 20% has been used, the operators know that the correct VAR to give the recommended dose is 0.5 l/ha, so it is calculated that 300 ha has been treated. This makes the large assumption that VAR and therefore dose were correct, whereas in reality, overdosing is often the case so the infested area treated may have been vastly over-estimated.

Methods of monitoring

Methods and systems must be found to improve the quality of monitoring. The whole process needs to be put on a more formal footing with the steps below being a possible approach which requires field testing.

An Ideal Approach to Field Monitoring

- Assigning responsibility - the task of monitoring and recording should be allocated to one particular person, most likely the graduate Field Officer supervising the control team or ground marker party activities. Things become more difficult when aircraft are spraying without ground party support, but efforts can still be made to get the aircrew to fill the form or to talk to them after spraying to get details for the form.
- Providing necessary equipment and the training to use it - the responsible staff member must have the necessary equipment and ability to carry out the monitoring. Equipment will

include clipboard, supply of forms and pens, GPS, compass, tachometer (if spinning disc sprayers are used), whirling hygrometer, anemometer, stopwatch or watch, bucket and measuring cylinder. Other equipment for monitoring control efficacy includes cages and sweep nets, .

- Use of standard forms - these are useful for standardising information collected and showing users clearly where information is missing or still to be collected. As with all forms, recording starts slowly as staff get used to a layout, but speed up rapidly as they become familiar with it. Not all of the form has to be filled in for every control target e.g. if sprayer settings have not changed, one form can refer to details on a previous form from earlier in the day.
- Collation and analysis of information - there is no point collecting information if it is not to be put to a useful purpose. There should be staff assigned at headquarters to collating the data and preferably entering the most important figures into a spreadsheet programme, or other data management software. Urgent issues requiring action can be dealt with immediately e.g. over-dosing, lack of protective clothing or major environmental impact, and other analysis can be dealt with later. The form also provide very useful data for reporting at the end of the campaign.

Practice This level of monitoring is yet to be tested in the field during Desert Locust control operations. Feedback is required from users on whether the form is practical - is the information being gathered too detailed, is some of it irrelevant or is there important information missing?

CHAPTER 4. MONITORING CONTROL EFFICACY

As has been mentioned earlier, feedback on the success, or failure, of control operations is very important to ensuring the eventual success of any campaign.

The effectiveness of control should be assessed during a control campaign. It does not have to be done accurately for every target, but spot checks should be made whenever possible, especially if new techniques or insecticides are being used. This feedback has three purposes: to assess whether a repeat spray is required to prevent the locusts escaping, to check that insecticide and control technique are effective - if the spraying is not killing the locusts, changes will have to be made before more (possibly equally ineffective) control is carried out. Thirdly, mortality estimates allow the efficacy of the campaign to be confidently reported.

Most of the time, an exact percentage mortality is not required for bands or for swarms - if there are very few locusts remaining alive after spraying, there is no need to spend more time. If it is clear that a substantial number of locusts are surviving control operations, it may be necessary to try to estimate the percentage kill so that fully informed decisions can be made and appropriate action taken e.g. repeat spraying or increasing dose in future operations..

Any quantification of partial kill is technically difficult because locusts can move out of the target area after spraying. This is especially true of highly mobile stages and with slower-acting products which allow the locusts to move much further before they die. There are also practical difficulties because, whatever the level of mortality assessment, the assessment team needs to re-visit the target some time after spraying to check it, usually at the end of the spraying day or the following day - the locust officers will probably be busy with other control operations in other areas at these times. Mortality measurements can only really be made on bands or settled swarms - assessing mortality of flying swarms is very difficult and in practice is limited to checking whether or not any significant swarm still exists the following day.

Other than the rough visual check to confirm good control, there are two main approaches to quantifying mortality of settled targets: field assessments and cage assessments:

Field assessments

Advice Estimates can be made of the number of locusts alive before and after spraying. Measuring the area of the target is not sufficient on its own because the same number of locusts occupy a different area at different times of day e.g. a marching band often covers a much larger area than a roosting band. The number of locusts is estimated by measuring the approximate size of the target and the average density of locusts in it.

Measuring the approximate size of the target

A similar method can be used as that for delimiting a target i.e. two transects are driven or walked at right angles to each other through the target to measure its length and its width so that the approximate area of the target can be calculated.

Measuring the average density of locusts in the target

Locust density can be measured by walking a transect and making at least 10 quadrat counts of the number of living locusts in 1 m^2 within the target (more quadrats for a large target such as a settled swarm) and the average number calculated. Decisions will have to be made on what is 'dead' and what is 'alive' but a rough guide is that if the locust is standing upright on the ground or clinging normally to vegetation, it is alive. If it is lying on its side or back on the ground, even if it not dead yet, the continued effect of the insecticide or heat of the sun or ants will usually kill it soon. This may not be the case with pyrethroids where there are reports of recovery from knockdown

An imaginary 1 m^2 quadrat can be estimated by spreading the feet apart to form a base about 1 m wide. A stick is useful for moving vegetation and flushing locusts underneath it. If locust numbers are large, an estimated ¼ m^2 can be used instead and the figure multiplied by 4 to give number per m^2. If the locusts are very mobile counting must begin before reaching the imaginary quadrat because locusts will jump or fly out of the quadrat before the person arrives. These assessments are really estimates which vary a lot in accuracy depending on time of day, mobility of the locusts and who is counting.

Both of these procedures should be carried out before spraying and at a suitable time after spraying. For conventional insecticides, this can be done several hours after spraying, The problems of field assessments of mortality are much greater for slow acting products such as IGRs and microbial pesticides. The post-spray counts will have to be done for several days after application and the locusts may have moved some distance in this time. The cage techniques described on the following pages are more practical for slow acting products and fast moving targets.

Calculations for field mortality assessments

Step 1. Calculate the average locust density from the 10 quadrat counts by adding them together and dividing by 10

Step 2. Calculate the area of the target by multiplying its length by its width

Step 3. Multiply the average density in the quadrats by the area of the target to get an estimate of numbers of locusts in the target.

Step 4. The approximate mortality is then calculated using the following formula:

$$\textbf{Approximate mortality (\%)} = 100 - \left(\frac{\text{post spray numbers x 100}}{\text{pre spay numbers}}\right)$$

If the product is fast acting and does not affect the behaviour of the locusts too much, it may be possible to carry out a mortality assessment which counts the dead locusts as well as the live ones. Provided there has not been too much removal of corpses by ants or cannibalism by other locusts, this should give a more accurate result than simply counting live locusts. The same imaginary quadrat technique is used, but dead as well as live locusts are recorded. The formula below can be used to calculate mortality.

$$\textbf{Approximate mortality (\%)} = \frac{\text{dead}}{\text{alive + dead}} \text{ x } 100\%$$

There is another technique for measuring low density locust populations called a 'flush count' - see The Desert Locust Survey Guidelines for details. It is not likely that any target worth spraying would have a locust density low enough for this technique to be used.

Practice Locust mortality is not often checked and is rarely quantified in any relatively accurate way after spraying. Again it remains to be seen whether this level of monitoring is achievable, even on an occasional basis.

Box 4. Summary of problems with field mortality assessments:

- If the insecticide affects locust behaviour e.g. makes bands disperse or seek shade, it may be difficult to assess mortality.
- Quadrat counts will flush locusts out of the counting area and therefore result in an underestimate of density
- It is sometimes not possible to count accurately the number of dead locusts since they may be scavenged quite quickly by ants or other organisms
- Locusts may move large distances before dying, especially if the product is slow-acting.
- Technique varies from person to person and if one person does the pre-spray count and another does the post-spray count, results will be inaccurate

Cage assessments

Where slower acting products are being used, or where roosting or milling adults are the target, cages can be a useful way of assessing mortality without having to chase the locusts after spraying.

Advice Estimates can be made of the number of locusts alive before and after spraying. Sprayed and unsprayed locusts are put into cages to see how many survive. These can be caught using a sweep net (either from a vehicle or on foot) but care should be taken to use a clean sweep net and not to drag it through the sprayed vegetation otherwise locusts will get an extra insecticide dose from the net. Various types of cage can be used. They can be made from clean plastic flasks (2 litres capacity) e.g. water bottles, with the tops cut off and holes made for ventilation. They can also be made using a wooden or wire frame covered in gauze.

Care should be taken to keep them in mixed sunlight and shade, to give the locusts some food and sticks to sit on, and to prevent ants or other predators entering and eating them. Put the cage feet into pots filled with water or oil. If the sprayed locusts were on vegetation, some of that sprayed vegetation should also be put into the cage - a locust often picks up an extra dose in the field by contact with, and feeding on, insecticide on the vegetation. If they are sprayed on the ground or on other surfaces, clean vegetation should be put into the cages. The same applies to the control cages with unsprayed locusts. If whole plants together with soil are put in and watered occasionally, the vegetation will stay fresh and continue to grow until eaten.

Field cages (similar but open at the bottom) can also be used. They are put onto living vegetation in the field and a number of locusts put in afterwards. Some researchers have tried throwing nets over settled adults on bushes after spraying.

A minimum of 8 cages should be kept. Six of these should contain sprayed locusts/vegetation and 2 unsprayed locusts/vegetation. Each cage should contain several insects (the number will depend on cage size, but a guide is 5-10 for a bottle and 15 - 20 for a large gauze cage). Dead and alive hoppers should be counted at intervals after spraying. If there is more than about 10% mortality in the control cages, the results are unreliable because they show that catching and/or caging has caused some additional mortality.

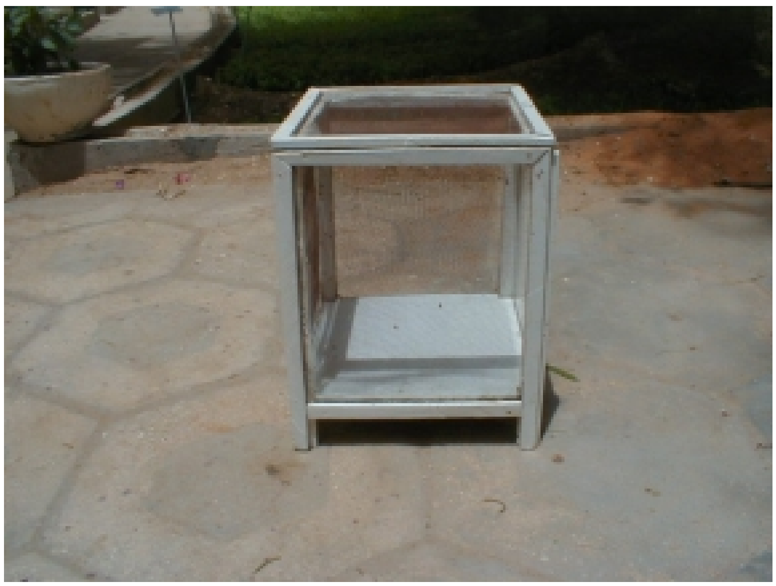

Plate 5 Cage design for mortality assessment

If a large block of bands has been sprayed using the barrier technique, it will be difficult to assess individual band mortality since it will not be known when they reach a sprayed barrier. In this case, it is possible to estimate the reduction in the total area covered by hopper bands within a large block. This requires careful sampling before and after treatment, which is difficult in a control campaign. A sampling method for this has not been described here, but it is similar to the 'point sampling' technique for estimating hopper infestation levels which is described in the Campaign Organization and Execution Guideline.

Practice Cage assessments are also rarely carried out due to pressures on staff during control operations and low prioritisation of mortality assessments.

Box 5. Summary of problems with cage assessments

- Predation by ants
- Cannibalism (one locust eating another)
- Mortality due to cage stress
- Mortality from contaminated sweep nets and/or cage materials
- Cages which cannot be dismantled are bulky to transport

Table 7 Mortality assessment techniques

Type	Target	When
Rough visual estimates in the field	Swarms and bands	Always after spraying
Pre and post-spray field assessments (density and target area measurements)	Bands	Occasional spot checks especially when new products, dosages or techniques are being used, or if there are control problems
Cage assessments	Swarms and bands	As above, especially when using slow acting products on fast moving targets.

CONCLUSIONS

FAO is well-placed to provide objective advice on best practice for Desert Locust control. Currently, this constitutes a synthesis of theory and research findings from many countries around the world, moderated by the field experience of many specialists in locust-affected countries. However, there is a stark contrast between what is recommended in the FAO Desert Locust Control Guideline and what is often practised by the majority of national Locust Control organisations. On one hand this is understandable and defensible since each country must find its own solutions to its specific problems, bearing in mind the constraints operating in that country. On the other hand, there are certain fundamental factors which are common throughout the Desert Locust territory - the laws of physics and the biology and behaviour of the locust - and it would seem that certain basic techniques should be utilised wherever Desert Locust control operations are being carried out. There seem to be two main problems:

Poor implementation of current recommendations on best practice

Control teams often do not follow current recommended practice. Reasons for this may be lack of resources, time, knowledge, motivation or management. Solutions include training to the level of existing knowledge, provision of appropriate equipment, maintenance, repair and adjustment of existing equipment, reorganisation of responsibilities within the control department incorporating management improvements and the implementation of monitoring , which can generate sufficiently detailed reports on activities and results. Consideration should also be given to incentive schemes by which control teams following best practices are recognised and rewarded. Some of these are being addressed through current training and assistance projects. It will be important to identify and train key individuals to be in overall charge of application technology for locust control, and to organise national training programmes for field staff in locust-affected countries. An important step will be to study in more detail the current control practices in different countries to identify the main problems, the capabilities of the control organisations and the requirements in order to improve things.

Inadequate recommendations on best practice

Best practice is not yet known for all types of locust spraying. Possible reasons for this are that ULV locust spraying is a specialised and recent technique which has relatively small commercial importance - it has not been well studied. Also, feedback on locust spraying is very limited. Sprayer and pesticide manufacturers, together with donors and locust-related organisations, are reluctant to invest heavily in determining the most efficient techniques when there is little documented evidence of, or complaint about, the major problems with current control operations. An additional factor limiting commercial involvement in the development of improved techniques for locust control is the limited and sporadic nature of the market for chemicals and equipment. There is little incentive for companies to invest time and resources in improving their products when the market for locust control is comparatively small most of the time. The solution is probably publicly funded research into some of the fundamentals of ULV locust spraying. Very little such research is currently being carried out.

Some of the aspects which are either unknown or presumed known on the basis of very little evidence include:

- drop size - what is the optimum drop size for locust spraying, is it different for different targets (hoppers/adults/settled/flying) or for different spray platforms (portable/vehicle/aerial)?
- drop spectrum - it is always presumed that a narrow drop spectrum is best but how narrow? Does the difference between spectra of air shear nozzles and rotary nozzles really have any practical significance?
- meteorological conditions - what are the temperature and windspeed limits for efficient spraying (ground and aerial)?
- spray sampling - which standard methods should be adopted for sampling the distribution and deposition of ULV locust sprays?
- spraying height - if this should be adjusted under different conditions, by how much?
- airblast or passive - in which situations does an airblast confer advantages and how significant are they in relation to their disadvantages? What other features of a sprayer are critically important?
- delimitation of targets - how can this best be done for different types of target?
- products - are some of the fast-acting contact insecticides better than others in certain situations?
- cocktails/synergism – the possibility of mixing fast knockdown pesticides such as pyrethroids from which locusts may sometimes recover, with pesticides which are slower acting such as the organophosphates or fipronil, deserves further investigation. There may be synergistic effects whereby the amount of each could be drastically reduced, such a combination may make it easier to assess the efficiency of control populations shortly after application.
- settled swarm spraying - what technique is best for different stages of swarms? Is the suggestion to spray twice at half the dose practical and more effective?
- air to air spraying - how can different types of flying swarms be sprayed?
- track spacing accuracy - how can this be achieved in different situations and how important is it?
- doses - do different types and stages of target required different doses?
- barrier spray parameters - what width and spacing of barriers will be effective for the different candidate products?
- mortality assessments - which techniques are best in which circumstances, and which are practical and possible in the midst of a busy control campaign?
- application monitoring - which aspects are the most important to record as feedback and as an archive of activities, and how can they best be collected?
- area infested/sprayed - what are the most practicable methods to estimate target area and area sprayed, rather than calculating it on the basis of pesticide used?
- ground teams for aerial spraying - what level of ground support is required and what should they do to carry out an efficient and sufficiently monitored operation?

- target location and marking - how can GPS technology best be used to improve locust spraying?
- what are the barriers, both technical and non-technical, which prevent Locust Control Organisations adopting best practice.

Some of these aspects, e.g. air to air spraying techniques, have to be studied on real locust targets in the field - often problematic because targets are unreliable and there is pressure to kill them rather than do research on them. But some of the other aspects can be initially researched in the absence of locusts e.g. drop size and spectrum, meteorological conditions, and optimum doses although the results have eventually to be verified in the field on real locust targets before the recommendations can be made.

With increasing scrutiny of the cost-benefit and environmental impact of locust control, it is all the more important to look beneath the surface of sketchy reports and to address the constraints to safer and more effective control. Locally appropriate information on best spray practice must be generated through an application research programme whose findings are disseminated through strengthened national Desert Locust control training programmes.

ACKNOWLEDGEMENTS

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ANNEX 1: TERMS OF REFERENCE

Under the supervision of the Senior Officer, Locusts and Other Migratory Pests, AGPP, the author will prepare a report comprising the following elements:

1) Listing and describing the various techniques currently used for controlling the Desert Locust with pesticides, including swarms of adults on the ground and in the air, hoppers and hopper bands. This applies to the equipment used (various spinners, nozzles, pressure tanks etc., for helicopters, aeroplanes, cars, hand held sprayers etc...), and different formulations and types of pesticides. Describing the advantages and disadvantages of the different methods in relation to their efficacy, their practical usefulness in relation to climatic conditions like wind and temperature, ease of transport, calibration, use and maintenance etc. In various types of terrain and distance from nearest pesticide store etc.

2) Listing and describing the various practices currently used in Desert Locust control, like block spraying, barrier spraying, direct target spraying in trees etc... identifying the advantages and problems with the different practices in relation to the target type and the terrain in which it is used. This includes methods for delimiting the target, finding the right direction for each swath, securing the correct application on basis of speed of vehicle, aircraft, men, etc.

3) Listing and describing various methods for monitoring efficacy of the spraying operations in terms of mortality, and the problems experienced with the various methods.

4) Identify the variables recorded during Desert Locust control operations, like climate, vegetation, locust parameters, spraying variables, safety etc., concentrating on the problems encountered finding their correct values in an easy and quick way, suggesting what is important for a successful control operation.

The report which is expected to be about 15,000 words in length and in English will be prepared electronically, preferably in Word 6 and will be sent as an e-mail attachment to the Locust Group, AGPP.

Sheet number on this day

ANNEX 2 : SPRAY MONITORING FORM

This form can be used to record details of all locust and grasshopper control operations (including dusting and baiting). Use a new form for each target treated. If many targets are treated in the same way each day, only fill in the boxes where details are different from the first target of the day.

Equipment required for monitoring spraying: Gloves, clipboard, blank copies of this form, pen, anemometer (for windspeed), tachometer (for speed of rotary atomisers), whirling hygrometer (for temperature/humidity), measuring cylinder, bucket, funnel, stopwatch, tape-measure, compass, GPS.

PERSONNEL			
Name of person filling form:	***Job title:***	***Date:***	
SPRAY LOCATION DATA			
Place (distance/direction from nearest town)	***Province/Governorate:***	***Latitude:***	***Longitude:***
LOCUST OR GRASSHOPPER DATA			
Species:	***Phase:*** Solitary ☐ Transiens ☐ Gregarious ☐	***Stage:*** Hopper ☐ Instar(s): 1☐ 2☐ 3☐ 4☐ 5☐ Adult ☐ Fledgling ☐ Immature ☐ Mature ☐	
Target type: Hopper band ☐ Swarm ☐ Patches ☐ Scattered ☐	***Target size*** ***(m^2, ha or km^2)***	***Density:*** Low ☐ Med ☐ High ☐	***Behaviour:*** Roosting ☐ Feeding ☐ Laying ☐ Marching ☐ Flying ☐ Copulating ☐
VEGETATION DATA			
State: Dry ☐ Greening ☐ Green ☐ Drying ☐	***% cover:*** 0-25 ☐ 25-50 ☐ 50-75 ☐ 75-100 ☐		
Type: Grass ☐ Bushes ☐ Trees ☐ Crops ☐ Crop type(s)	***% Crop damage***		
INSECTICIDE DATA			
Common name e.g. fenitrothion:	***Trade name e.g. Sumithion:***	***Concentration (g a.i/l or %):***	***Expiry date:***
Formulation: ULV ☐ EC ☐ Dust ☐ Bait ☐ Other ☐ (please specify)			
Is the insecticide mixed with water or other solvent? Yes ☐ No ☐ ***If 'Yes' what solvent and mixing ratio?***			

WEATHER CONDITIONS	***Time***	***Temp. (^{o} C)***	***Relative humidity %***	***Windspeed (m/s)***	***Winddirctn (degrees)***	***Spray dirctn (degrees)***
Start of control operation						
End of control operation						
Rainfall around spraying time? Yes ☐ No ☐ ***If 'Yes' when and how much?***						

SPRAY APPLICATION DATA

Name of supervisor of control operation:

Locust control training courses attended: National course ☐ Regional course ☐ FAO course ☐

Other ☐ (please specify)

Sprayer platform: Aerial ☐ Vehicle ☐ Operator-carried ☐ Other ☐ (please specify)

Type of sprayer: Rotary ☐ Airblast or Exhaust ☐ Conventional Nozzle (hydraulic) ☐

Other ☐ (please specify)

Sprayer operator: Pilot ☐ Driver ☐ Locust Officer ☐ Farmer ☐ Hired labour ☐
Other ☐ (please specify)

Sprayer manufacturer	***Sprayer model***	***Sprayer calibrated:*** Today ☐ ***If not today, when?***	***Atomiser height above ground (m):***

For airblast sprayers, airblast direction: Upwards ☐ Sideways ☐ Downwards ☐

For rotary atomisers, speed setting (e.g. blade angle, pulley setting or number of batteries):	***Speed of atomiser rotation (rpm):***

Flow rate setting (e.g. nozzle, restrictor):	***Flow rate per atomiser (l/min):***	***Number of atomisers:***

Track spacing (m):	***Forward speed (km/hr):***	***Area sprayed (m^2, ha or km^2):***

Which edge did spraying start? Downwind ☐ Upwind ☐	***Spray volume used (litres):***
For aerial spraying, ground party available to assist: Yes ☐ No ☐	***Radio communication with aircraft:*** Yes ☐ No ☐

Method of ground marking for aircraft: None ☐ Flags ☐ Mirrors ☐ Smoke ☐ Vehicles ☐

Other ☐ (please specify)

CONTROL EFFICACY DATA

Mortality checked Yes ☐ No ☐	***Time 1***	***Time 2***	***Time 3***	***Time 4***	***Time 5***
Time after treatment (hrs)					
Locust mortality (%)					

Method of mortality estimation: Quadrats ☐ Size of locust target ☐ Visual estimate ☐ Cages ☐

Other ☐ (please specify)

SAFETY AND ENVIRONMENTAL DATA

People involved in spraying:	***Driver*** ☐	***Operator*** ☐	***Technician*** ☐	***Other staff*** ☐	***Farmers*** ☐
Did they wear: gloves	☐	☐	☐	☐	☐
Overalls or full length clothes	☐	☐	☐	☐	☐
Boots or shoes to cover feet	☐	☐	☐	☐	☐
Mask	☐	☐	☐	☐	☐
Goggles	☐	☐	☐	☐	☐

Soap and water available for washing? Yes ☐ No ☐	***Inhabitants, herders, bee-keepers informed of spraying?*** Yes ☐ No ☐
Any people feeling sick or unwell during/after spraying (e.g. staff or farmers)? Yes ☐ No ☐ ***If Yes, describe in detail:***	***Any non-target organisms affected by spraying (e.g. livestock, birds, lizards, fish):*** Yes ☐ No ☐ ***If Yes, describe in detail:***

Problems encountered and other comments:

Please submit this form to your locust HQ as soon as possible after spraying.