Desert Locust Guidelines

4. Control

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PREFACE

The Desert Locust plague of 1986-89 and the subsequent upsurges in the 1990s demonstrate the continuing capability of this historical pest to threaten agriculture and food security over large parts of Africa, the Near East and southwest Asia. They emphasize the need for a permanent system of well-organized surveys of areas that have recently received rains or been flooded, backed up by control capability to treat hoppers and adults efficiently in an environmentally safe and cost-effective manner.

The events of 1986-89 showed that, in many instances, the existing strategy of preventive control did not function well, for reasons including the inexperience of the field survey teams and campaign organizers, lack of understanding of ultra low volume spraying, insufficient or inappropriate resources and the inaccessibility of some important breeding areas. These reasons were compounded by the general tendency to allow survey and control capacity in locust-affected countries to deteriorate during locust recession periods. To address this, FAO has given high priority to a special programme, the Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases (EMPRES), that will strengthen national capacities.

Given the certainty that there will be future Desert Locust upsurges, FAO produced a series of guidelines primarily for use by national and international organisations and institutions involved in Desert Locust survey and control. The guidelines comprise:

1. Biology and behaviour
2. Survey
3. Information and forecasting
4. Control
5. Campaign organization and execution
6. Safety and environmental precautions

Appendixes (including an index) are provided for easy reference by readers.

This second edition has been produced to update sections on technology and techniques that have undergone changes in the seven years since first publication, to modify presentation of the material, to make it easier to understand and to facilitate updates in the future. The revision was carried out by K. Cressman of FAO and H.M. Dobson of the Natural Resources Institute, United Kingdom, with input from many locust and locust-related specialists around the world. This edition will be available in the three key languages of the locust-affected countries, English, French and Arabic.

I would like to extend my gratitude to all those who have been involved in this important contribution to improved Desert Locust management.

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Contents

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INTRODUCTION

This guideline is intended mainly for use by field staff involved in Desert Locust control operations, including field officers supervising control operations and pilots and engineers of spray aircraft. Some parts will be useful reference material for training new staff and providing refresher training for experienced locust officers. The information and reference data may also be useful for senior managers planning and overseeing campaigns and for donor representatives assessing technical needs.

The guideline contains practical advice on equipment and techniques used to carry out locust control which is safe (minimum negative effect on humans and the environment), effective (controls locusts successfully) and efficient (effective with minimum cost). Some basic scientific explanation is given where necessary. During the 1987-89 plague, over 90 percent of insecticide was applied by ultra low volume (ULV) spraying, and this guideline concentrates on this method, although high volume spraying, baiting and dusting are mentioned.

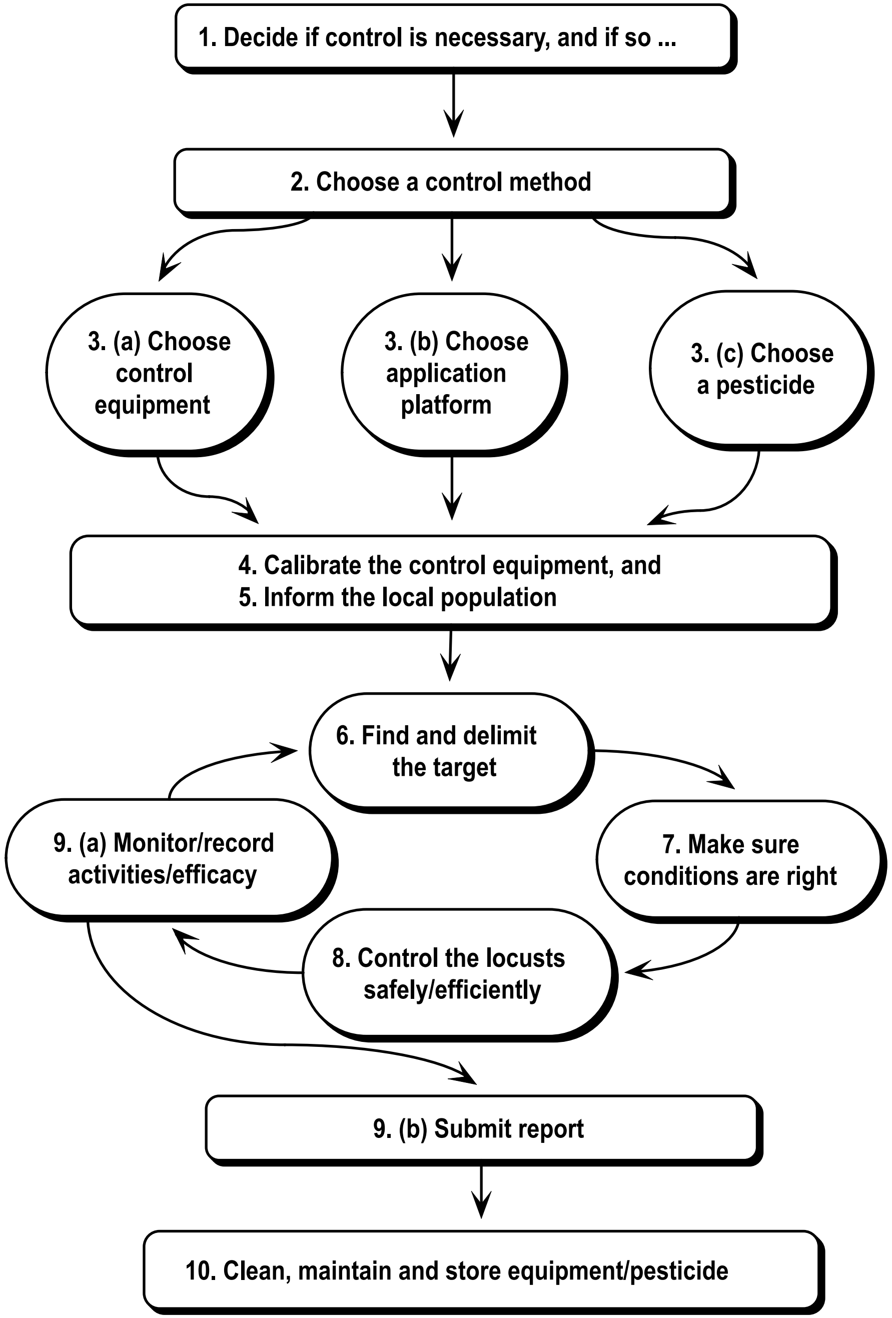
The basic principles of ULV spraying are relatively simple and the advice given here should give good results in most cases. However, individual control situations vary widely in practice and the ideal spray parameters are not fully known for all of them. Locust control staff in the field must also understand the theory explained here in order to make informed decisions on whether to spray and on how to modify their technique to cope with the many different circumstances they will encounter.

Information, advice, procedures and explanations are given on the right-hand pages of the publication; illustrations and summaries are given on the left-hand pages. When appropriate, tips and warnings may appear on either side.

There is also a series of Frequently asked questions (FAQs). These deal with some of the common problems encountered by locust field staff. Answers are given where available, but further research is needed in some areas, and FAO welcomes feedback on new information and solutions.

Much of the information given here is relevant to the control of other species of locust and some grasshoppers, but techniques may have to be adapted to match the particular characteristics and habitat of the target species.

Figure 1. Summary of the control process.



CONTROL PROCESS

A logical approach is required in order to avoid unnecessary, wasteful, dangerous and ineffective control operations.

When locusts are found, there are a series of steps that need to be followed before, during and after the control operations (see Fig. 1):

Step 1. Decide whether control is necessary. This will depend on the type of target and where it is – see p. 4-5.

Step 2. If control is necessary, decide upon the scale and timing of the operation required. This will depend on factors such as how big the infestation seems to be, how urgent it is to get started and how quickly the infestation must be treated – see p. 4-5.

Step 3. Choose a control method, i.e. equipment, insecticide and technique. The method will depend on factors such as size of infestation and urgency, but also on what resources are available – see p. 6-33.

Step 4. Calibrate the control equipment so that the correct amount of insecticide is applied in the right way to the right place – see p. 34-45.

Step 5. Ensure that control will be safe to people and the environment – local populations should be informed so that they can move livestock, beehives and people away. Operators should use protective clothing and should identify and avoid sensitive ecological areas. See Safety and environmental precautions guideline for more details.

Step 6. Find and delimit the target, i.e. locate the locusts and mark the boundaries of the infestation – see p. 46-51.

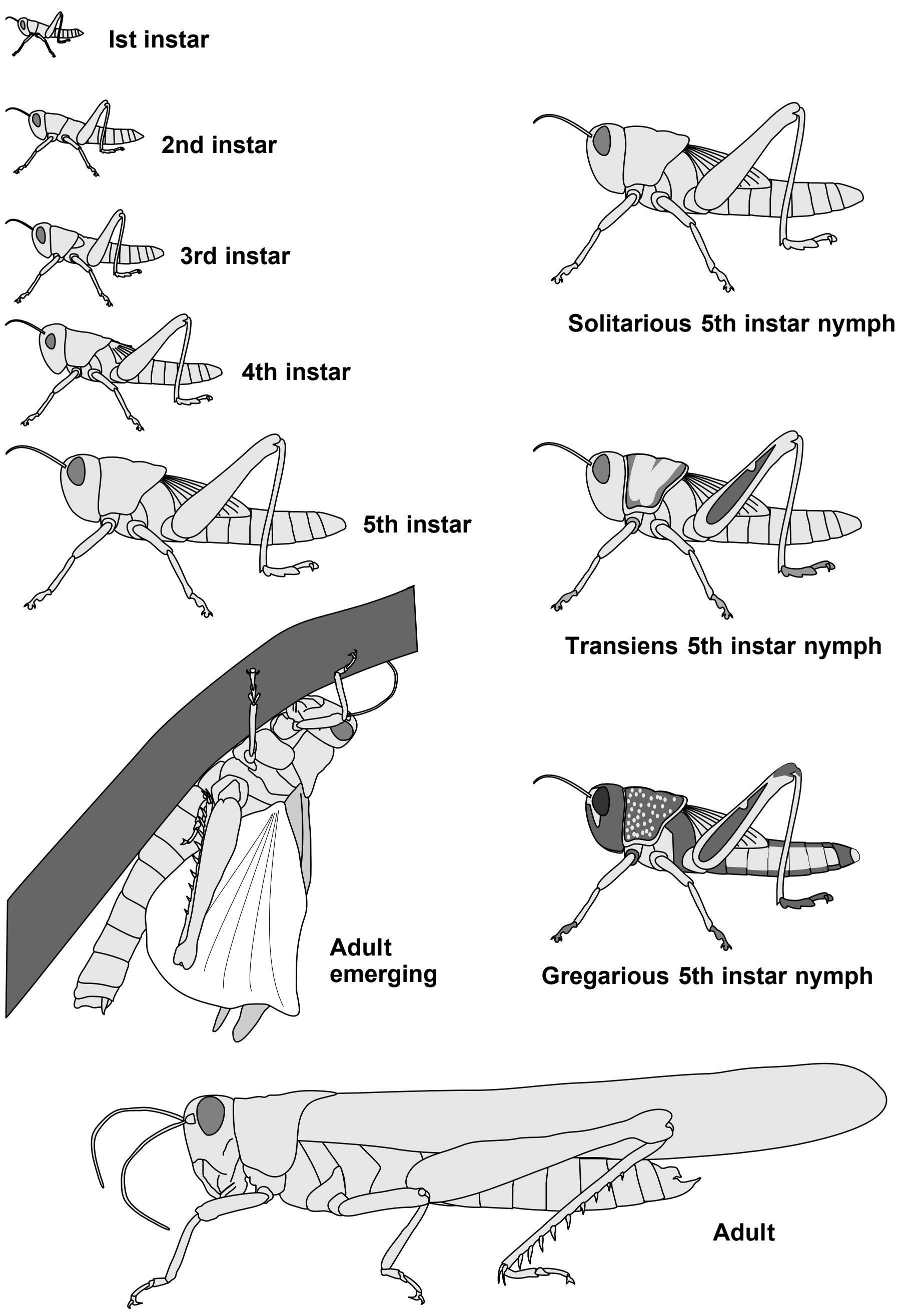
Step 7. Check that weather conditions are suitable for the control method – see p. 52-53.

Step 8. Carry out the control – see p. 54-69.

Step 9. Monitor control operations and efficacy and record all relevant details for inclusion in a control report – see p. 70-79.

Step 10. Clean, service and store equipment. Store unused insecticides safely – see p. 80-81.

Figure 2. Nymphal instars and phases of the Desert Locust – life size.



IS CONTROL NECESSARY?

What is the control target and where is it?

Desert Locusts may be nymphs, also called hoppers, or they may be winged adults. They may be in solitarious phase (dull-coloured and living individually) or in gregarious phase (contrasting coloration and tending to gather in groups). Gregarious groups of nymphs are called hopper bands and large groups of adults are called swarms. Locusts may also be in a transiens phase – somewhere between solitarious and gregarious phases. Adults may either be sexually mature i.e. ready to mate and lay eggs or immature (see the Biology and behaviour guideline for more details).

It is not possible to give hard and fast rules on when to control locusts; this will have to be the decision of the locust control staff. The decision will be based on the age, phase and maturity of the locusts (see the Biology and behaviour guideline for details), as well as on their number and density, and other factors such as closeness to vulnerable crops and likelihood of breeding. However, it is usually very wasteful to control solitarious and other low-density locusts scattered over a large area – almost all the insecticide will miss the locusts. It may be more sensible to wait to see if they group together and form better targets after a few days or if they die when conditions become unfavourable. Some locust control organizations base control decisions on threshold numbers of locusts per hectare but these may need to be modified according to the specific situation. The decision may also be influenced by ecological or environmental considerations.

If control is necessary, what factors will influence the methods used?

- *Size of infestation*. If the targets are small and few in number, they can be controlled using low speed, simple methods. However, if the infestation is heavy and widespread, a method is required to treat large areas quickly i.e. a method with a faster work rate.
- *Stage of locusts*. If they are adults, a quick response and fast work rate are usually required to prevent them migrating to other areas, especially if they are sexually mature.
- *Where they are*. If bands or swarms are close to crops, there is even greater need for a method that can start quickly and give rapid results. There is also the opportunity for valuable assistance from the farming community.
- *What resources are available for control*. Sometimes the most appropriate equipment or materials are not available at the right place at the right time and control must be carried out with whatever is available.

Summary of locust control methods:

- mechanical methods – digging trenches, beating and burning
- baiting – scattering locust food impregnated with insecticide
- dusting – applying a fine dust impregnated with insecticide
- spraying liquid insecticides (chemical or biological)

Advantages and disadvantages of different control methods

Advantages	Disadvantages
mechanical	
● low cost ● low environmental impact ● no specialist equipment required	● slow ● often ineffective ● labour intensive
baiting	
● insecticide well targeted at locusts ● little specialist equipment required	● large quantities of bait required ● arduous mixing process ● slow application
dusting	
● little specialist equipment required	● large quantities of dust required ● slow application ● control may be poor ● inhalation risk to operators
spraying	
● faster work rate ● liquid insecticides give more rapid and reliable control	● spraying equipment required ● training and protective clothing required for safe and effective control

CONTROL METHODS

Mechanical control

Methods such as digging trenches for hoppers to fall into or beating hoppers with branches are sometimes used as a last resort to try to protect crops. They may prevent some crop damage if the locust infestation is light, but they have little effect on the overall population in the region and can fail to protect crops when there are many locusts continuously invading the fields. 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 previous swarm laying sites.

Baiting

This method was popular up to the 1950s but has been used very little in recent years. It involved mixing insecticide dust with a carrier such as maize meal or wheat bran, and scattering the mixture among or in the path of the locusts. 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). There may also be a risk to livestock that might eat the bait.

Dusting

Dusting involves mixing pesticide dust with a material such as powdered chalk or talc and scattering it on the locusts. 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. However, many countries have given up dusting because of 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. There is also a health risk to operators who may accidentally inhale the dust.

Spraying

Spraying is the most commonly used method for locust control. It involves using a sprayer to atomize a liquid pesticide, i.e. to break it into droplets, which are then distributed over the target area. Some different types of spraying are described on the following pages.

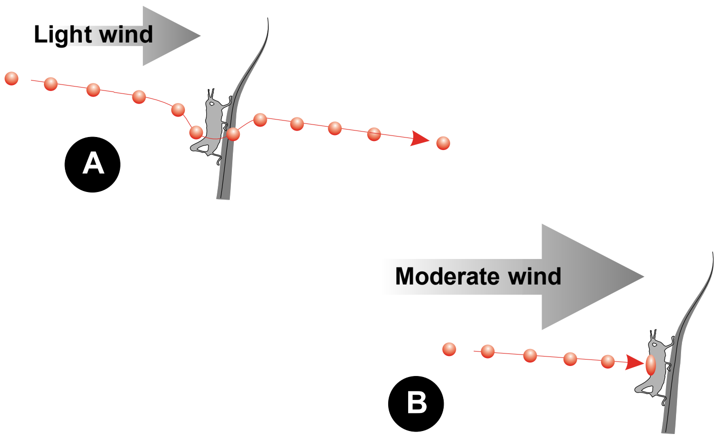
Summary of characteristics of ULV spraying:

- ultra low volumes (0.5-5.0 l/ha, compared with hundreds of litres for other spraying)
- oil-based formulations to stop evaporation
- no mixing since the ULV formulation is usually supplied ready to spray
- the wind carries droplets to the target and impacts on it
- some pesticides have a high concentration of active ingredient

Advantages and disadvantages of ULV spraying

Advantages	Disadvantages
• small volumes of liquid to transport and apply • water is not required • no mixing required • fast work rate – economic benefits	• operator risk (concentrated spray) • cannot spray without wind • specialized sprayers required • spray may drift a long way

Figure 3. Small droplets do not hit objects in their path if the wind is very light, but will impact on objects in stronger winds.



SPRAYING

Water-based spraying

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) or other type of formulation. Water-based spraying is rarely carried out on a large scale against Desert Locusts because the work rate (number of hectares treated per hour) is low and the large volumes of clean water are difficult to find in most Desert Locust habitats.

Ultra low volume (ULV) spraying

A technique using much smaller volumes 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 and commonly used method. It is defined as applying between 0.5-5.0 litres of spray liquid per hectare, although between 0.5 and 1.0 l/ha is preferred for ULV locust control. This small quantity of concentrated insecticide is not mixed with water or any other liquid; the special formulation, known as a ULV (or UL) formulation, is usually supplied ready to spray.

In order to spread such small volumes over the target, 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 that are typical during locust control operations, ULV formulations are based on oil rather than other solvents such as water or petrol fractions which may be too volatile, i.e. evaporate too quickly.

These small droplets do not deposit (land on surfaces) very easily. They fall very slowly, so tend to be carried sideways by the wind rather than sedimenting (raining down) on to horizontal surfaces. In addition, if they are too small or the wind is too light, they tend to go around objects rather than hit them, somewhat like smoke (see Fig. 3A). However, if the droplets are the right size and there is sufficient wind, they deposit by impaction on vertical surfaces such as vegetation or locusts (see Fig. 3B).

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FAQ number 1 (see p. 82 for answers)

What is the spray target – the locusts or the vegetation?

Summary of characteristics of large and small droplets

Droplet size	Advantages	Disadvantages
Large	• deposit in target area • impact easily • low evaporation	• very few droplets per litre • are not spread well by wind • fall mainly on the ground
Small	• many droplets per litre • well spread by wind • land on leaves/insects • good crop penetration	• drift out of target area • poor impaction on objects • evaporation is greater

Figure 4. In Desert Locust habitats, droplets of the correct size impact on vegetation and locusts. Very large droplets usually fall on the ground and very small droplets can be carried out of the target area by the wind.

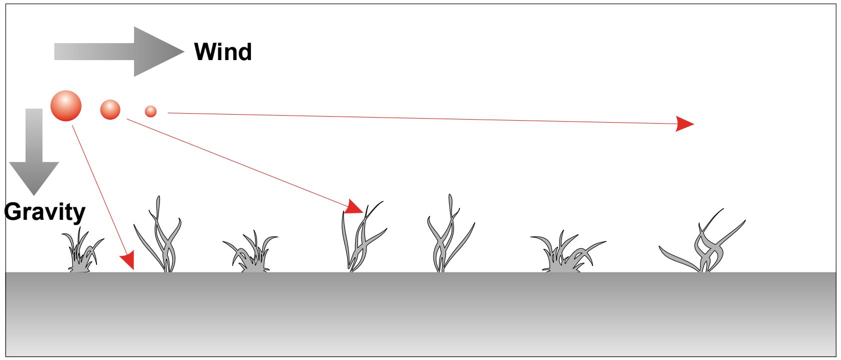
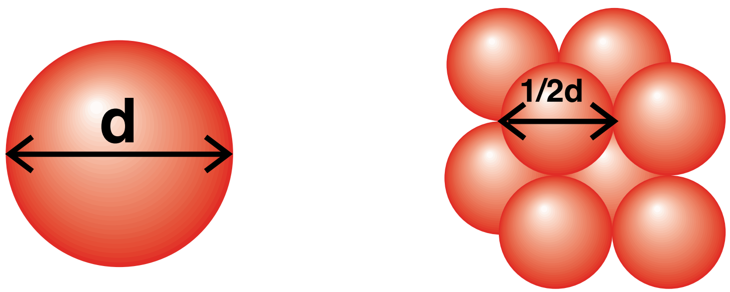


Figure 5. One large droplet can make eight smaller droplets of half its diameter each.



ULV SPRAYERS

Special sprayers are required for ULV spraying if the insecticide is to be used safely and efficiently. Several important factors must be considered:

- droplet size (depends on the atomizer)
- droplet spectrum (depends on the atomizer)
- work rate (depends on the sprayer platform and flow rate)
- operator safety (depends on various design features)
- ease of use (depends on various design features)
- reliability (depends on construction materials and design)

Droplet size

One of the most important components of the sprayer is the part that makes the droplets, i.e. the atomizer, since the droplets must be of the right size to be effective.

If droplets are either too large or too small, control may be poor and insecticide will be wasted. Large droplets fall much more quickly than small droplets. Figure 4 shows that droplets that are too large fall on the soil near the sprayer, droplets of the right size are carried some distance by the wind and are more likely to impact on vegetation and/or locusts, and droplets that are too small are blown out of the target area.

Large droplets also contain a large volume of insecticide so that when they fall on the ground, they are very wasteful. A large droplet contains sufficient insecticide for eight droplets of half its diameter so if droplet size is increased, the number of droplets per litre is greatly decreased (see Fig. 5).

The size of a droplet is usually expressed in terms of its diameter, i.e. the distance across the droplet. It is usually measured in micrometres, also sometimes called microns and the unit is written µm. There are 1 000 micrometres in one millimetre and ten millimetres in a centimetre. A full stop in these guidelines is around 200 µm in diameter.

The ideal droplet diameter for locust control is thought to be between 50 and 100 µm, but this is a very large range and there is little field evidence of exactly which size is best under different circumstances.

Tip: in still air a 200 µm droplet will take less than 5 seconds to fall 3 m, whereas a 20 µm droplet will take almost 5 minutes.

Figure 6. Volume median diameter (VMD). This is the diameter where half the volume of spray is in larger droplets and half the volume is in smaller droplets.

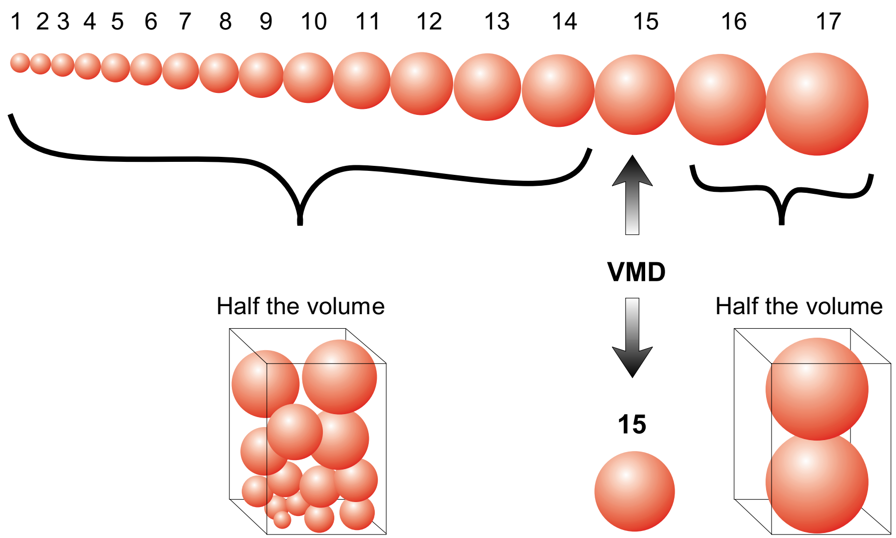
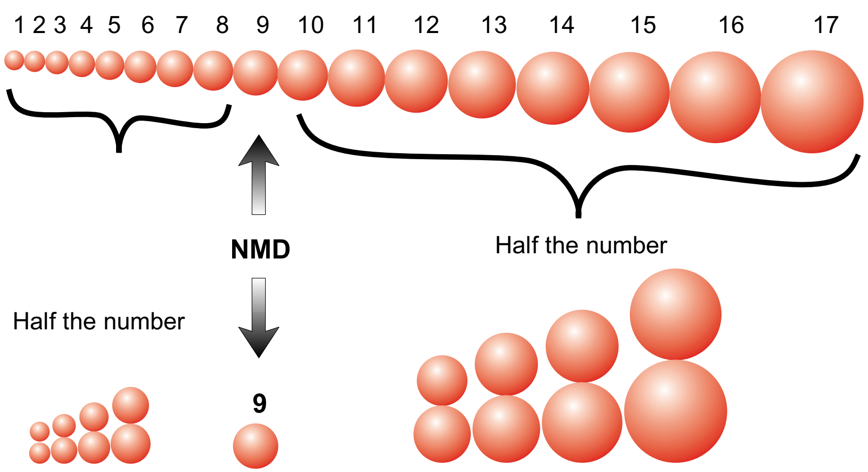


Figure 7. Number median diameter (NMD). This is the diameter where half the number of droplets are larger and half the number of droplets are smaller.



Droplet spectrum

If there were 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 there is a large difference in size between the smallest and largest droplets. A narrow droplet spectrum contains droplets of approximately the same size with little size difference between the smallest and the largest droplets. A narrow droplet spectrum is best for ULV spraying. This is because large droplets contain relatively large volumes of pesticide yet usually fall on the ground near the sprayer, and very small droplets may be carried out of the target area by wind (see p. 10 and 21).

Droplet spectra are usually described using the values of volume median diameter (VMD) and number median diameter (NMD) (see Figs. 6 and 7 for definitions). These are both types of average used to represent the range of droplet sizes in the spectrum: one is based on the volume of the droplets, the other on the number of droplets.

The ratio (R) of VMD and NMD values gives a rough measure of the width of the droplet spectrum – the nearer it is to 1, the more similar 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:

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

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

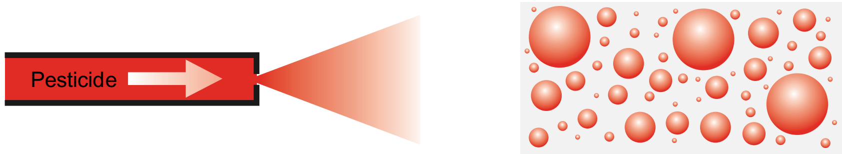
Another way of describing a good droplet spectrum for ULV locust control is to say that it should have at least 80 percent of the spray volume in the size range 50-100 µm. Only certain types of sprayer can achieve this.

> ***Tip: measuring droplet sizes and the droplet spectrum is not easy and requires specialized equipment and training. However, droplet spectrum information is available from some ULV sprayer manufacturers.***

Figure 8. Simplified diagrams of the main types of locust control atomizer and the type of droplet spectrum each produces.

A. Hydraulic nozzle, e.g. on a lever-operated knapsack sprayer

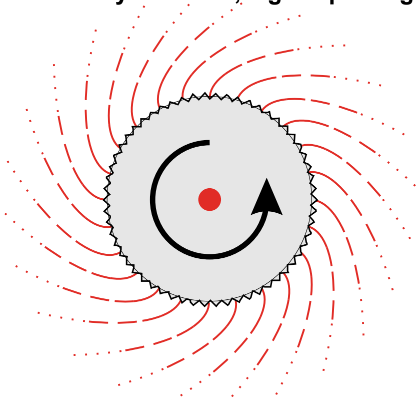
R = more than 2.5
(very poor for ULV spraying)



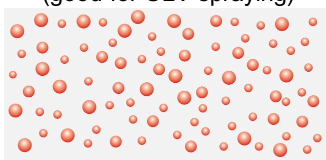
B. Air-shear nozzle, e.g. on a motorized knapsack sprayer or an ENS

R = more than 2.0
(poor for ULV spraying)

C. Rotary atomizer, e.g. a spinning disc or a spinning cage



R = between 1.2 and 2
(good for ULV spraying)



Choosing an atomizer

The three main types of atomizer available for locust control are:

Hydraulic nozzles

Liquid is forced under pressure through a small hole and is broken up into droplets as it comes out (see Fig. 8A). Hydraulic nozzles are commonly found on lever-operated knapsack sprayers and on tractor/aircraft spray booms. Generally, the droplet spectrum from hydraulic nozzles is not suitable for ULV spraying since the droplets are usually large (VMD 200-400 µm) and the droplet spectrum is very wide (R is more than 2.5). Smaller droplets can be produced by smaller nozzles, higher pump pressures and the air shear caused by aircraft-mounted nozzles moving through the air at flying speed, but droplet spectrum will still be quite wide.

Air-shear nozzles

Liquid is released from a pipe into a blast of air that breaks the liquid into droplets (see Fig. 8B). Air-shear nozzles are often used on knapsack mist blowers. The exhaust nozzle sprayer (ENS) has a type of air-shear nozzle with the airblast provided by exhaust gases from the spray vehicle (see Appendix 1.10). It is possible to achieve smaller droplets (VMD 40-200 µm), but the spectrum is still quite wide (R is greater than 2), so this type of atomizer is not efficient for ULV spraying. Faster airblasts produce smaller droplets.

Rotary atomizers

Liquid is fed on to a rotating surface that throws the liquid off in droplets (see Fig. 8C). The faster the rotation, the smaller the droplets. Some rotary atomizers have spinning discs that produce a very narrow droplet spectrum, especially if they have teeth on the edge (R as low as 1.2). Droplet spectrum is narrowest with a low flow rate and, if a greater flow rate is required, several discs can be stacked one behind the other. Other rotary atomizers have spinning gauze 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 are more robust (strong and reliable) in the field than discs.

Rotary atomizers are the most efficient type of atomizer for ULV spraying.

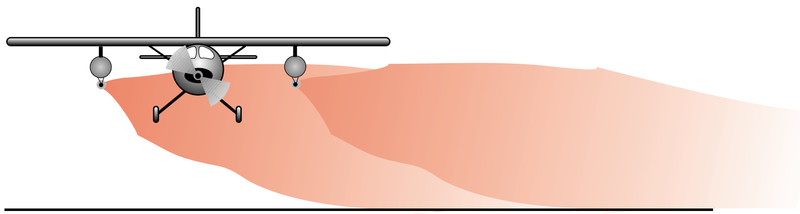
Typical values for VMD:NMD ratio (R)

● hydraulic nozzle	R = more than 2.5 (very poor)
● air-shear nozzle	R = more than 2.0 (poor)
● spinning cage	R = 1.7 (good)
● spinning disc	R = 1.2 (very good)

Figure 9. Different types of sprayer platform.

A. Portable ULV sprayer

B. Vehicle-mounted ULV sprayer



C. ULV sprayer

> ***Tip: aerial spraying with helicopters is almost the same as with fixed-wing aircraft, since the down draft of air is the same when they are flying at spraying speed. Helicopters do have some advantages (see FAQ number 2), but they are more expensive to operate, have a shorter range and are slower, so they should only be used when really necessary.***

Choosing a sprayer platform

A platform carries the sprayer. ULV 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 or helicopter (aircraft-mounted sprayer). The principle of use is the same for all of them, but the scale and speed of operation and certain practical limitations are different. The table below compares the performance of the three platforms. In practice, during a control campaign, different sprayer platforms can be combined; for example, a vehicle-mounted sprayer can travel with three or four handheld spinning disc sprayers. The vehicle sprayer sprays the larger targets while portable sprayer operators can dismount to treat small patches and targets in difficult terrain.

Characteristics of different sprayer platforms

Performance factor	Portable	Vehicle	Aircraft
Work rate?	slow	medium	fast
(full coverage spraying)	(15 ha/day)	(100 ha/day)	(5 000 ha/day)
Speed of response?	fast	fast	can be slow
Spray in rocks/hills?	yes	no	yes
Spray on 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
Involve community?	possible	possible	no
Appropriate target size? [1]	up to 10 ha	1-100 ha	over 25 ha

[1] individual targets that could include parts of swarms or hopper bands

?

FAQ number 2 (see p. 82 for answers)

When should helicopters be used instead of fixed-wing aircraft?

Summary of important factors in choosing a sprayer:

- droplet size (must give 50-100 µm VMD and narrow droplet spectrum)
- work rate (must be high enough for the type of target)
- access to target (e.g. portable or aerial platforms for hills/sand dunes)
- efficiency (e.g. aerial spraying is not suitable for individual bands)
- flow-rate range (must be high enough and low enough)
- operator safety (must be safe for staff using it)
- reliability (must continue to function in tough conditions)
- practicality (must be easy to calibrate, use, service and clean)

Tip: the sprayer should be appropriate to the target size. It is inefficient to spray individual hopper bands with an aircraft because the minimum treated area is still much larger than most bands, and it is also difficult to judge exactly where most of the insecticide from a single spray pass is depositing.

Tip: most locust sprayers do not meet the requirements listed above, but an understanding of the ideal sprayer can help with more efficient use of existing sprayers and can assist with decision-making when new sprayers are being bought or manufactured.

Other sprayer factors

Appropriate flow rate

The sprayer flow rate must be adjustable to apply the right volume of insecticide on each hectare, i.e. provide a volume application rate (VAR) between 0.5 and 1 l/ha. In practice this means flow rates in the range of 0.015-0.15 l/min for a handheld sprayer, 0.05-1.0 l/min for a vehicle-mounted sprayer and 4-50 l/min for an aircraft sprayer. Flow rate should also be easily measurable and quickly adjustable so that it can be checked and set regularly (see the Sprayer flow rate section on p. 43 and Appendix 2.5).

Operator safety

The sprayer must be safe for the operator. For example, an operator should not have to go close to the vehicle sprayer to turn it on and off. Controls should be mounted inside the vehicle cab.

Reliability

Locust sprayers should be of a rugged and durable design since they will be used in rough conditions, often far from a workshop. Maintenance will, however, be necessary from time to time, so routine servicing and replacement of parts must be possible in the field without special tools or facilities.

Practicality

The sprayer must be practical to use in the field. An example of a sprayer that is not practical would be one where the insecticide tank is very small so that frequent refilling is necessary. Another example would be a sprayer with poor access to the filters, making them difficult to clean.

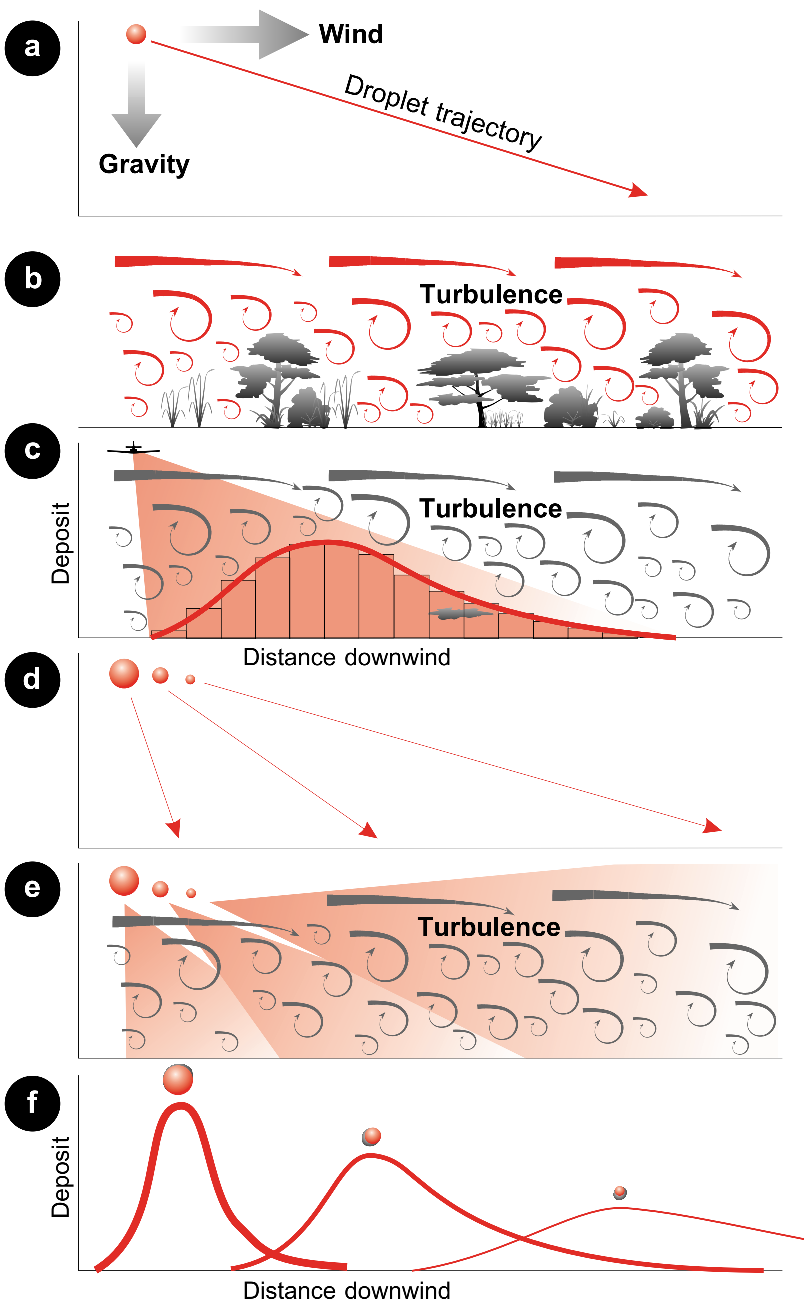
Appendix 1.10 gives some information on several types of sprayer that have proved safe, efficient and reliable for Desert Locust control. Results from a sprayer performance evaluation carried out by participants of an FAO workshop are shown in Appendix 5.4.

?

FAQ number 3 (see p. 82 for answers)

What can the spray team do if there are no sprayers with rotary atomizers available or working, i.e. only sprayers with hydraulic or air-shear nozzles?

Figure 10. Factors affecting where droplets go.



SPREADING ULV SPRAY EVENLY OVER THE TARGET

A good ULV sprayer produces droplets in a small size range (narrow droplet spectrum) and these are carried downwards by gravity and sideways by the wind (see Fig. 10a).

This does not mean that droplets of the same size will all deposit at the same distance from the sprayer. When the wind passes over the ground surface, especially if vegetation is present, it causes turbulence, i.e. mixing of the air (see Fig. 10b).

This turbulence mixes the droplets upwards and downwards so that some are deposited close to the sprayer and some far away from it. This produces a deposition profile shown by the bar chart and curve in Fig. 10c. Small amounts are deposited near the sprayer, building up to a peak some distance downwind, then tailing off further downwind.

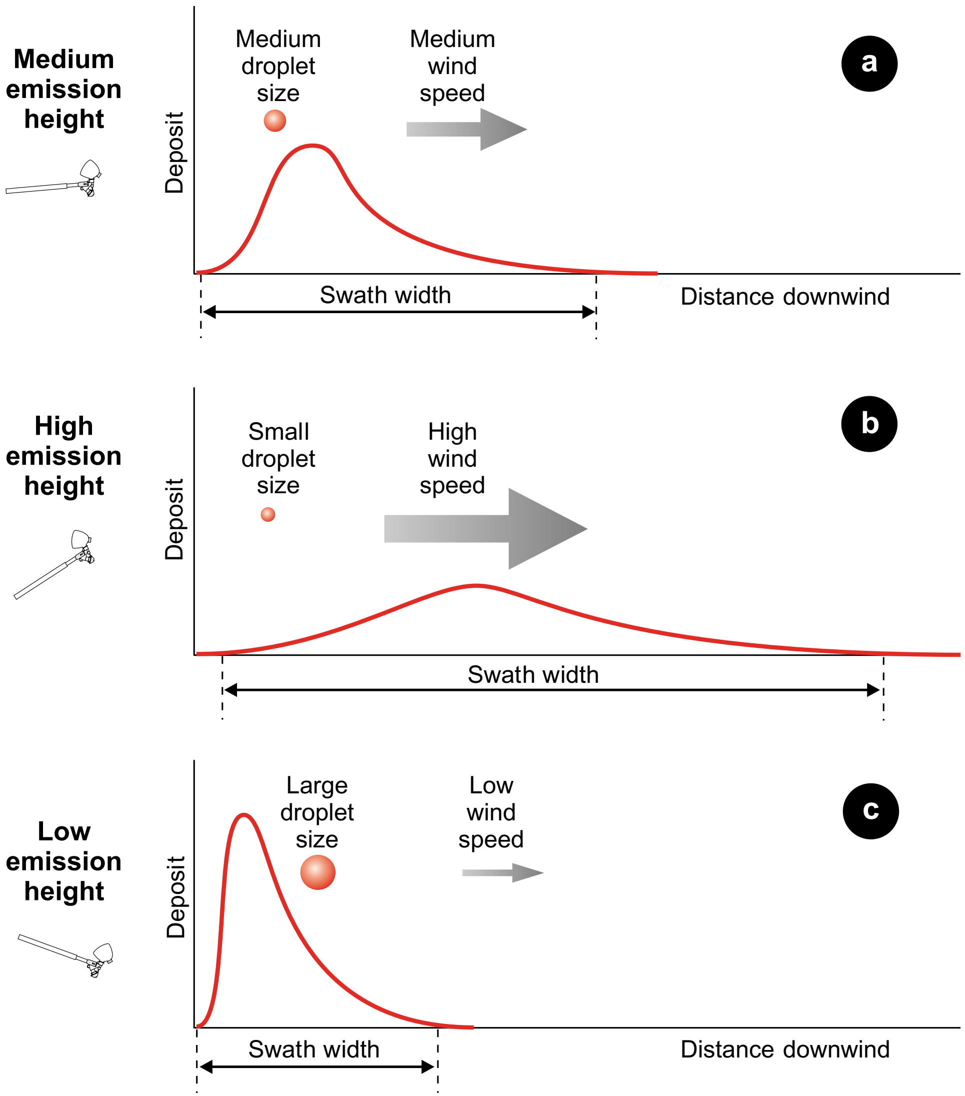
Some ULV sprayers have the advantage of an adjustable droplet size (VMD) so a different size can be chosen for different situations. Even a good ULV sprayer produces a range of droplet sizes. These different droplet sizes behave in different ways – the smaller droplets (which fall more slowly than large droplets) are usually carried further by the wind (see Fig. 10d).

Although turbulence is useful for droplets in the right size range because it helps to spread them more evenly over the target area and carry them deep into vegetation, very small droplets fall so slowly that turbulence may carry some of them upwards (see Fig. 10e) so that they drift away and do not deposit in the target area.

Typical downwind deposition profiles in the presence of turbulence from three different droplet sizes are shown in Fig. 10f.

Tip: however much turbulence there is, the downwind deposit from a single spray pass is always very uneven.

Figure 11. Factors affecting swath width.



Swath width

If the amount of spray deposited at different distances downwind from a typical ULV sprayer is plotted on a graph, it usually looks something like Fig. 11a. The distance over which most of the spray is deposited is known as the swath width.

However, the swath width for a particular sprayer is not an exact measure since it varies with conditions and settings. If the wind is very strong, if the sprayer is very high, or if the droplets are very small, the swath will be much wider (see Fig. 11b). If the wind is light, the sprayer is low or the droplets are large, the swath width will be very narrow (see Fig. 11c).

Although the swath width varies, it is a good idea to measure it under a range of different conditions to gain an understanding of the performance of the sprayer under these different conditions. Appendix 2.4 describes a procedure for measuring the approximate swath width from a ULV sprayer.

Even when conditions are good and the correct emission height and droplet spectrum are used, the deposition is not the same at all parts of the swath, i.e. the deposition is not uniform or even. The deposit starts low, builds up to a maximum quite close to the sprayer, then tails off over a long distance downwind. For barrier spraying, this unevenness may not be important. However, for efficient full coverage spraying, we need to make this deposit more uniform (less stripey) otherwise some parts of the target area will receive an overdose (too much insecticide), and other parts an underdose (too little insecticide), possibly not enough to kill the locusts.

Factors affecting swath width

- emission height – the higher the emission, the wider the swath
- droplet size – the smaller the droplets, the wider the swath
- wind speed – the stronger the wind, the wider the swath
- turbulence – the greater the turbulence, the wider the swath

Figure 12. The only way to achieve a reasonably uniform total deposit is to use a track spacing less than the swath width so that spray from each pass overlaps the deposit from the previous passes.

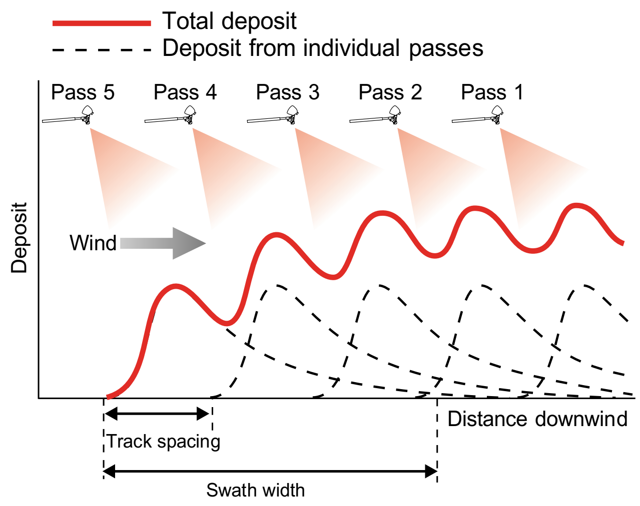
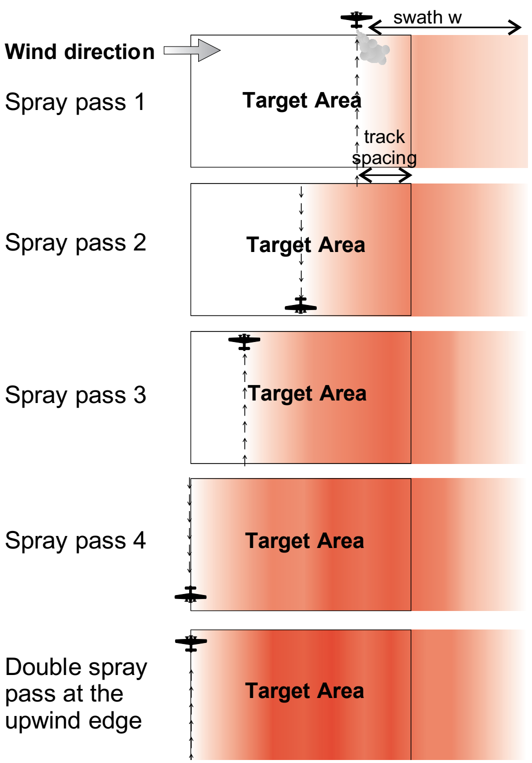


Figure 13. As swaths overlap, the deposit builds up in the target area to give a reasonably uniform total deposit.



Track spacing

The method used to make the deposit less variable over the target area is to overlap the swaths by making the track spacing (the distance between one spray track and the next) less than the swath width (the distance over which most of the spray is deposited). The result is shown in Fig. 12. In this case a handheld sprayer uses a track spacing of less than half of the swath width in order to overlap the swaths and give a total deposit which is more uniform. The choice of track spacing will vary according to conditions and must be made by the Field Locust Officer in charge of the spraying on that day. Remember, a larger track spacing gives a faster work rate but a less uniform deposit. Appendix 5.3 gives recommended track spacings for normal spraying conditions for different types of sprayer. Note that the upwind edge of the block still has a lower deposit than the rest of the block, so under real spraying conditions, either a double spray pass should be made at the upwind edge or an extra spray pass made upwind of the target.

Tip: if you know the approximate swath width for a sprayer under particular conditions, using a track spacing between a half and a third of the swath width will give a reasonably uniform total deposit.

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FAQ number 4 (see p. 82 for answers)

How many spray droplets must deposit on the vegetation or on the locust to be sure of a reliable kill?

Characteristics of the main types of insecticide

- Conventional insecticides (organochlorines, organophosphates, carbamates, pyrethroids): fast, reliable, but full cover spray usually required. Some are dangerous to operators and environment.
- Insect growth regulators (IGRs): slower acting, barrier spraying possible and relatively safe to operator and environment.
- Newer conventional products such as fipronil: slower acting, barrier spraying possible and relatively safe to operators because of low formulation concentrations.
- Botanicals (extracts from plants): slow action and incomplete kill.
- Semiochemicals: pheromones may produce useful behavioural or developmental changes, but no direct kill. They are still being researched.
- Biological agents such as *Metarhizium* spp: even slower acting at present, but very low risk to operators and environment.

Mammalian toxicity of pesticides

Mammalian toxicity of pesticides is measured in terms of the dose that will kill 50 percent of a test population of mammals, e.g. rats, in the laboratory. It is presumed that this gives an indication of toxicity to humans. This measure is known as the LD50 and the toxicity is expressed as the quantity of product per kg of body weight of the test animals. The tests are done both for an oral dose, i.e. eaten by the test animals and a dermal dose, i.e. put on the skin of test animals. For example, fenitrothion has an oral LD50 of 503 mg/kg which means that if a number of rats weighing 1 kg are each fed 503 mg, half of the test population will die.

A pesticide such as bendiocarb has a lower oral LD50 of 55 mg/kg, which means that a smaller quantity will kill half of the test population – bendiocarb is more toxic.

The actual toxicity of the spray also depends on the concentration of the formulation being used – for example, the active ingredient of some pyrethroids have a relatively low LD50 and are therefore quite toxic, but are supplied in such dilute concentrations that the formulation is not very toxic at all. If the formulation is a solid, the toxicity is usually much lower.

The risk to operators using pesticides depends on these two factors – inherent toxicity of the active ingredient and formulation concentration – but also on the degree of exposure to the formulation.

CHOOSING AN INSECTICIDE

Most of the locust control carried out in the last 40 years has used conventional chemical insecticides (organochlorines, organophosphates, carbamates and pyrethroids). They work either by direct contact action (droplets land on the locusts) or by secondary contact action (locusts touch the droplets on the vegetation) or by stomach action (locusts eat the sprayed vegetation). The insecticides are usually neurotoxic, i.e. they kill the locust by interfering with its nervous system.

However, there are some newer chemical and biological products which offer advantages such as lower environmental impact, lower operator hazard and greater logistical efficiency, e.g. large areas can be treated in a short time.

Some of the characteristics that need to be considered when choosing locust control insecticides are:

- efficacy – the more toxic the active ingredient (the poisonous part of the insecticide) is to the locusts, the smaller the amount of active ingredient needed.
- safety – the product should ideally have a low toxicity to mammals (humans, livestock) and to other animals such as birds and fish.
- specificity – ideally the product should be toxic to locusts but not to other types of arthropod. If they are toxic to many other types of arthropod they are called broad spectrum compounds.
- persistence – the longer the product remains biologically active in the field, the more effective it is because it can kill locusts later as they emerge from eggs or arrive in the area. However, there may be a more serious effect on other organisms, i.e. greater environmental impact, from a persistent product.
- route of entry – whether it is a contact or stomach action product will determine its suitability for different targets, e.g. flying swarms need a product with contact action.
- speed of action – the faster the product works, the less crop damage will be caused and the better the feedback the control team has on the effectiveness of operations. However, sometimes speed of action is not important, e.g. for hopper bands far from crops.
- shelf life – the longer a product can be stored before use the better. If it is not needed immediately it will still be effective in future years.
- availability – locust insecticides must be available as ULV formulations in large quantities at short notice.
- cost – insecticides are one of the most expensive elements in any control campaign so cheaper products will greatly reduce control costs.

Tip: remember that the lower the LD50, the more toxic the pesticide. (see page26)

Advantages and disadvantages of the main types of conventional insecticides for locust control

Advantages	Disadvantages
Organochlorines	
• persistent	• dangerous to humans and the environment – **not recommended**
Organophosphates and carbamates	
• medium mammalian toxicity • quite fast acting (2-8 hrs) • some have low cost	• some dangerous to mammals • some kill birds and fish • broad spectrum
Pyrethroids	
• fast knockdown • low mammalian toxicity	• locusts may recover after knockdown • broad spectrum
Mixtures or cocktails	
• combine good features of two insecticides	• more complicated to calculate dose and calibrate • broader environmental impact

Tip: to assess the mammalian toxicity of a pesticide, check the hazard classification given by the World Health Organization (WHO). Pesticide active ingredients have been classified as extremely hazardous, highly hazardous, moderately hazardous or slightly hazardous depending on their LD50. The remaining products are classified as unlikely to cause acute hazard under normal use. A summary table of LD50 values for these classifications is given in Appendix 3.3.

Conventional chemical insecticides

There are three commonly used types of active ingredient (a.i) – the toxic part of insecticides.

Organochlorines

BHC, DDT, dieldrin and endrin are examples. They are generally broad spectrum (they kill many types of arthropod), are persistent in the environment (several weeks for dieldrin on desert vegetation) and can build up in the bodies of animals. This makes them hazardous to the environment and to mammals such as humans and livestock (dieldrin is WHO class 1b, highly hazardous) and the use of most organochlorine pesticides is not recommended for locust control or other pest management. See Appendix 3.3 for WHO classifications.

Organophosphates and carbamates

These are currently the most widely used type of locust insecticides, e.g. fenitrothion, malathion, chlorpyrifos and bendiocarb. These insecticides are quite fast-acting (two to eight hrs), relatively non-persistent, but quite broad spectrum compounds. Most of the ones used for Desert Locust control are moderately hazardous to mammals (WHO class II) but malathion is WHO class III, slightly hazardous.

Synthetic pyrethroids

Examples are deltamethrin, lambdacyhalothrin and esfenvalerate. They are fast-acting (knockdown within minutes), have varying levels of persistence and are broad spectrum. Recovery of locusts from knockdown has been reported but this may be where less than the recommended dose has been used or where application was poor. Formulations are of fairly low mammalian toxicity – most are in WHO class III, slightly hazardous.

Mixtures, also known as cocktails

Some locust insecticide formulations contain a mixture of two of the above types of insecticides (each at a lower dose) to exploit the useful characteristics of both. An example is fenitrothion and esfenvalerate which combine the knockdown effect of the pyrethroid with the slower efficacy of the organophosphate.

Tip: chemical insecticides are referred to in these guidelines by the common name of their active ingredient which always has the first letter in lower case, e.g. fenitrothion. The name of the formulation produced by a particular manufacturer always starts with a capital letter, e.g. Sumithion and it is this brand name, also called trade name, which is registered by national registration authorities.

Advantages and disadvantages of new and alternative products for locust control

Advantages	Disadvantages
Insect growth regulators (IGRs), e.g. diflubenzuron, teflubenzuron	
● persistent ● very low mammalian toxicity ● quite low environmental impact ● selective due to stomach action	● slow action (>3 days) ● little effect on adult locusts ● effects on freshwater arthropods
Phenylpyrazoles, e.g. fipronil	
● persistent ● formulations have relatively low mammalian toxicity ● stomach and contact action	● slow at low doses (1-2 days) ● broad spectrum – many other non-target arthropods are affected
Chloronicotinyls, e.g. imidacloprid	
● formulations have relatively low mammalian toxicity ● stomach and contact action	● little data available yet for Desert Locust control
Botanical insecticides, e.g. neem	
● can be produced at village level in small quantities ● low environmental impact	● slow action and usually incomplete kill ● limited commercial availability ● quality assurance difficult
Semiochemicals	
● pheromones may be highly specific and safe products	● no direct kill or evidence of other operational efficacy ● none available commercially
Biopesticides, e.g. Metarhizium anisopliae var. acridum	
● low mammalian toxicity ● highly specific – safer to environment ● possibility to produce locally formulation	● very slow action and variable locust mortality ● may have short shelf life or difficulties ● difficult to produce in large quantities rapidly and cheaply

Tip: safer products should be chosen for application through portable sprayers because of the greater risk of operator contamination.

New and alternative types of chemical insecticide

Some other types of chemical product with useful new characteristics have recently been introduced or are undergoing testing for locust control.

Insect growth regulators (IGRs)

IGRs such as diflubenzuron, teflubenzuron and triflumuron interfere with production of chitin, the hard material in insect cuticle. As a result the insect dies because it cannot make the new cuticle when it moults. IGRs are very safe for mammals (WHO classes them as unlikely to present acute hazard) and there is little effect on other organisms such as birds and fish. They are also quite selective since the route of entry is mainly via the stomach, thus plant-eating insects receive a greater dose than beneficial insects such as parasitic wasps or bees. IGRs are persistent, remaining active on vegetation for several weeks and are effective barrier spray products. However, they are slow-acting, they kill some species of arthropod in fresh water and they are not effective against adult locusts because adults have finished moulting.

Phenylpyrazoles

Fipronil is one of this new type of insecticide which is undergoing extensive testing. It interferes with the normal functioning of the insect's central nervous system. Fipronil is persistent and effective as a barrier spray product against hoppers. It is also effective against adults, but has a relatively slow action at low doses. It is broad spectrum and affects many other species of arthropod, but is fairly safe for mammals because it is used at low concentrations, and has low toxicity to fish and birds.

Chloronicotinyls

The new insecticide imidacloprid has been shown to be effective against *Locusta migratoria capito,* but insufficient data are available in relation to the Desert Locust at present. It acts on the insect's nervous system in a different way from other products.

Botanicals

Naturally occurring products such as the extract from the neem tree are potentially useful as insecticides and/or anti-feedants. Mortality is slower and usually lower than with conventional insecticides. The mixture of active ingredients in locally produced neem extract is very complex and varies from batch to batch, and it would be difficult to produce sufficient quantities to combat a large-scale locust infestation at short notice.

Semiochemicals

Locusts produce pheromones that cause responses in locusts of the same species. Some of these pheromones influence insect interactions, so it may be possible to use them to reverse the process of gregarization or to disperse bands and swarms. Various other effects of experimental application have been seen, such as reduced feeding and marching, increased predation and cannibalism and increased susceptibility to insecticides and pathogens. However, their control efficacy has not been demonstrated and no products are available commercially.

FAO support for development of products for Desert Locust control

- FAO produces an advice booklet on the protocol for Desert Locust control trials in the field. This contains a summary of procedures and equipment for carrying out a rigorous insecticide trial against Desert Locusts that meets required scientific standards and gives hints on producing a good field trial report.
- FAO also produces an advice booklet on grasshopper control trials. These are similar, but describe techniques more suited to less mobile insects. The value of grasshopper trials is that they can be carried out during times when there are few locusts and the data can be used as supporting evidence of the efficacy of the pesticide against the Desert Locust.
- FAO hosts a panel of independent specialists called the Pesticide Referee Group (PRG) which reviews locust and grasshopper field trial reports and data. The PRG prepares a report with a list of locust pesticides and their efficacy in terms of proven dose rates, environmental effects and other data. The most recent list is presented in Appendix 3.1. New field trial reports and other relevant information should be sent to the PRG which usually meets annually so that the locust insecticide data can be updated.
- FAO has managed a large project in Senegal funded by the Netherlands, investigating the environmental side effects – or ecotoxicology – of some of the most common locust control insecticides. Some of the data from this project is included in Appendix 3.1 and some of the useful ecotoxicological techniques developed during the course of the project are described in the Safety and environmental precautions guideline. More information is available on the internet (www.fao.org/news/global/locusts/locustox/ltoxhome.htm).
- FAO organized a workshop in Cairo in which locust control specialists from 12 countries evaluated locust sprayer performance in the field. The results are shown in Appendix 5.4.

Tip: FAO does not recommend, approve or register any pesticide for Desert Locust control. Those listed in Appendix 3.1 have been shown to be effective at the doses specified by good field trials or long field experience. In these guidelines, this dose is referred to as a **recommended dose**. ***There are many other products that are effective against the Desert Locust but they have not yet demonstrated their efficacy at a particular dose in well-executed field trials. FAO will not participate in or support in any way the use of pesticides which have been withdrawn, such as dieldrin.***

Biopesticides

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 the locusts. An attractive possibility is to establish 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 in order to kill the whole population. Even if this cycling does not occur, biopesticides are still attractive since they are likely to be quite specific to locusts and have little impact on humans, livestock or the environment.

Possible biopesticide products include:

- bacteria – no *Bacillus thuringiensis* (BT) strains have been found to be effective and some other bacteria that infect locusts may be harmful for humans.
- virus – there are some entomopox viruses that 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 grasshohppers but efficacy has been disappointing in the field so far.
- fungi – mitosporic fungi such as *Metarhizium anisopliae* var. *acridum* have been the most successful of the biopesticides tested so far. They can be produced *in vitro*, i.e. in non-living materials, by a solid state fermentation process with simple equipment. *Metarhizium* has good contact action, unlike any of the other candidate biopesticides and a strain has been developed and registered as a ULV 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 – this organism also attacks other types of insect.

FAO information on locust insecticides

See summary box on the left for details of FAO support to the development of new products for Desert Locust control. FAO will send the latest version of the information in Appendix 3.1 if requested. Alternatively, visit the FAO web site (www.fao.org/news/global/locusts/locuhome.htm) for updates.

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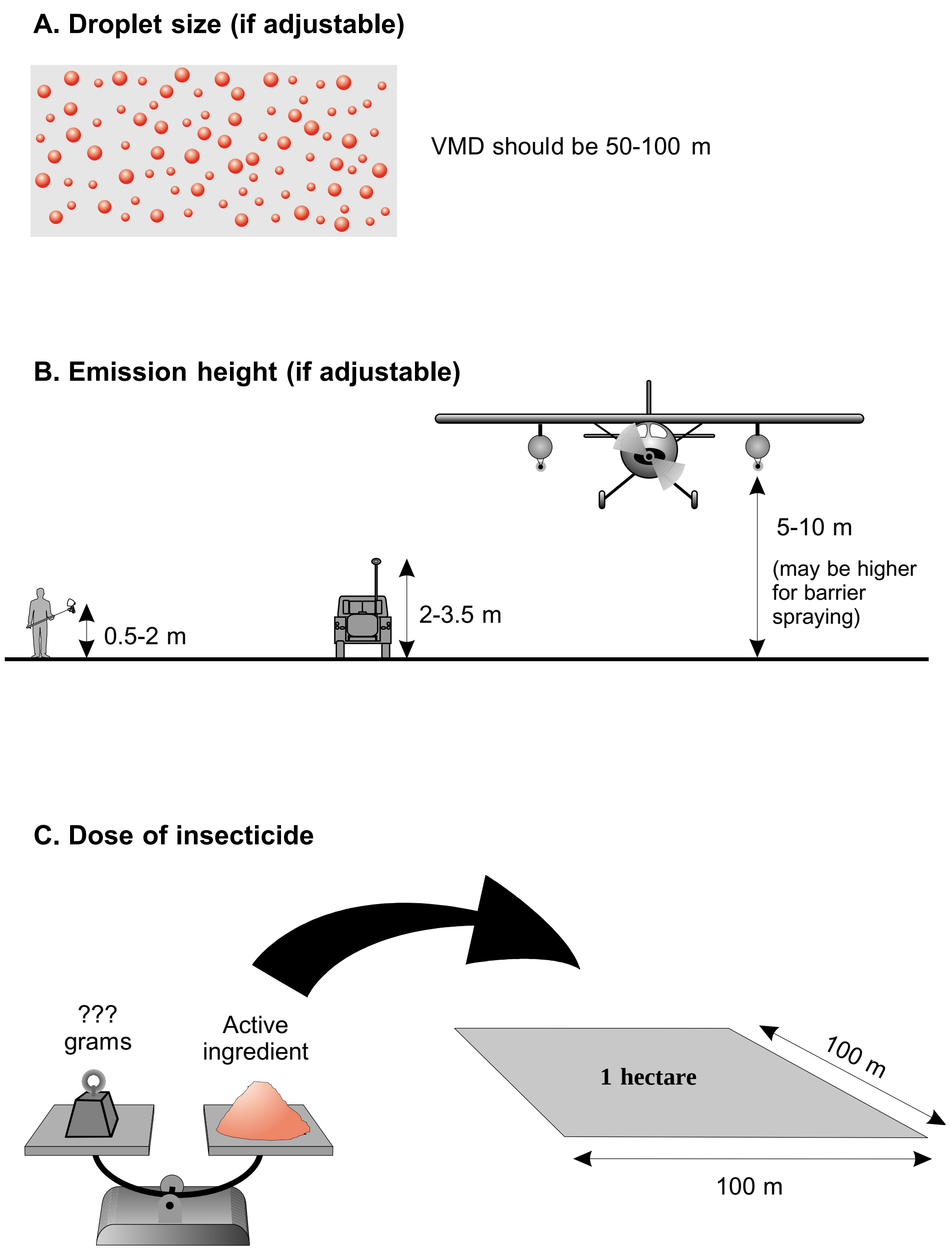
FAQ number 5 (see p. 82 for answers)

What criteria do the Pesticide Referee Group use to judge insecticide trial reports?

Figure 14. Factors in calibration – droplet size, emission height and dose.



CALIBRATION FACTORS

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. Three factors need to be calibrated to achieve an efficient result (see Fig. 14).

Droplet size

It is necessary to check that the sprayer is adjusted to produce a droplet size that will spread and deposit well over the target area and deposit reasonably well on locusts and/or vegetation (current recommendation is a VMD of 50-100 µm). Since measuring droplet size requires special equipment and training, in practice, the atomizer is usually set to produce a rotational speed that will produce an assumed droplet size according to the manufacturer's handbook. The droplet size may have to be adjusted for different spraying situations.

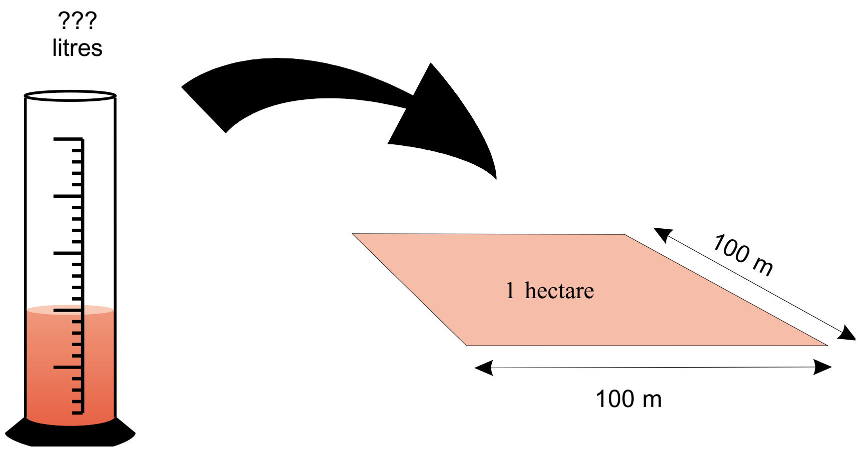
Emission height

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, the wider the swath, but if the emission 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 when possible. Depending on the wind speed, emission height for handheld sprayers should be 0.5-2.0 m, for vehicle-mounted sprayers 2.0-3.5 m (although most are not adjustable) and for aircraft 5-10 m. The emission height for aircraft will have to be higher for milling/flying swarms and possibly for barrier spraying too. Similarly it may have to be higher to allow for undulating terrain, tall trees or other obstacles. Vehicle-mounted airblast sprayers can be angled up or down to alter the effective emission height (up to around 8 m).

Recommended dose of insecticide

The dose is the quantity of active ingredient (the poisonous component of the liquid) applied to an area of land, usually expressed in units of grams of active ingredient per hectare (g a.i./ha). The recommended dose is the amount known to be sufficient to kill the locusts reliably without wasting too much pesticide. This will usually be given on the pesticide label. If no dose guidance is given on the pesticide label, Appendix 3.1 shows the current FAO list of recommended doses for locust control products, as determined by the Pesticide Referee Group and based on long field experience and/or good trials. If there is no recommended dose, the manufacturer should be contacted for guidance or field trials carried out to establish a dose.

Figure 15. Volume application rate (VAR).



Tips:

- ***for portable sprayers, pesticide formulations with a VAR of 1 l/ha or more should be used as they are likely to be less concentrated and therefore less toxic to the operators than those applied at 0.5 l/ha.***
- ***many people apply more insecticide than is needed because they are not familiar with calibration methods, and they wish to see the locusts die quickly. Remember that the correct dose will kill the locusts reliably but with some conventional insecticides mortality may take several hours or even days.***

ACHIEVING THE RECOMMENDED DOSE

Calculating the required volume application rate (VAR)

In order to achieve the recommended dose for a given insecticide formulation, the volume application rate (VAR) has to be regulated, in other words the volume of liquid sprayed per hectare. The required VAR depends on the recommended dose (g a.i./ha) and on the concentration of active ingredient in the formulation (g a.i./l), and can be calculated using the following formula:

$$\textbf{Required VAR (l/ha)} = \frac{\textbf{recommended dose (g a.i./ha)}}{\textbf{formulation concentration (g a.i./l)}} \qquad \textit{Formula 1}$$

For example if a formulation of bendiocarb contains 200 g a.i./l, Appendix 3.1 shows that the recommended dose for bendiocarb is 100 g a.i./ha, and so the VAR can be calculated using Formula 1 as below:

$$\text{Required VAR (l/ha)} = \frac{\text{100 g a.i./ha}}{\text{200 g a.i./l}} = \text{0.5 l/ha}$$

This means that if 0.5 litre of bendiocarb 200 g a.i./l formulation is applied to each hectare, the recommended dose of active ingredient will be successfully applied to each hectare

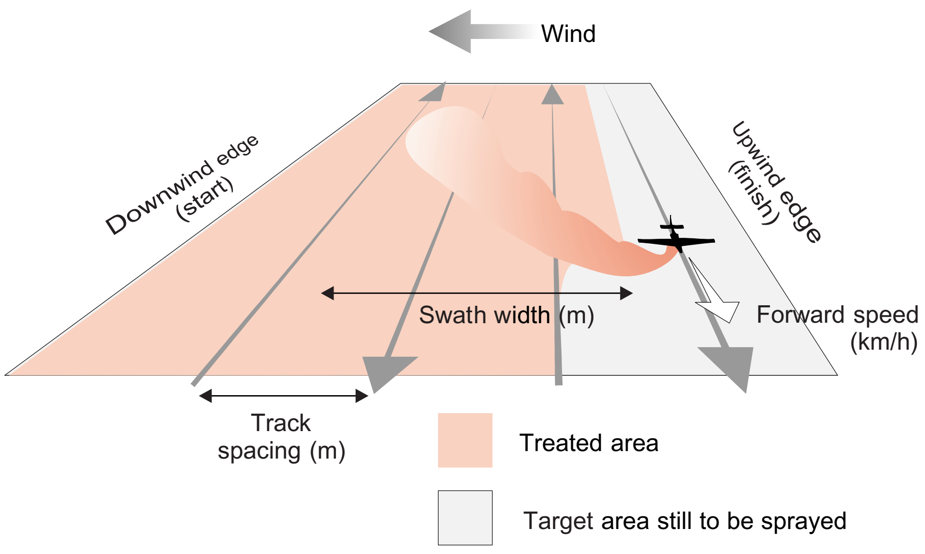
Tip: if the calculated VAR is far below 0.5 l/ha, it will be necessary to dilute the formulation with a relatively non-volatile solvent such as cottonseed oil in order to produce sufficient droplets.

?

FAQ number 6 (see p. 82 for answers)

Do different stages of locusts – early instars, late instars, adults – require a different dose of insecticide to kill them in the field?

Figure 16. Diagram showing terminology used in calibration.



Tip: the work rate of a sprayer is the area it can treat per hour. There is usually no need to calculate this but a rough estimate can be derived using the following formula:

$$\text{Work rate (ha/h)} = \frac{\text{Forward speed (km/h)} \times \text{track spacing (m)}}{10}$$

However, this does not take into account time to move between spray tracks at the end of each spray pass, so the actual work rate will always be less than this. In the case of aircraft, the work rate will be much less since turning time takes up a significant proportion of the flying time and ferry time for refuelling and refilling pesticide will also be additional.

Calculating sprayer settings to achieve the required VAR

In order to apply the required volume application rate (VAR) as calculated using Formula 1, three spraying factors must be set (see Fig. 16):

- track spacing – the distance between spray passes.
  If track spacing increases, VAR decreases.
- forward speed – the speed that the sprayer is moving.
  If forward speed increases, VAR decreases.
- flow rate of the sprayer – the volume of pesticide being emitted by the sprayer each minute, also called emission rate.
  If flow rate increases, VAR increases.

It is important to understand the relationship between these factors – sprayer operators may need to be advised on flow rate, track spacing and forward speed to achieve the correct VAR and dose for insecticides they have not used before. Also, if conditions change and one of these factors has to be changed, it will be necessary to adjust one or both of the other factors to maintain the correct VAR and the recommended dose.

For example, if the wind becomes stronger, it might be possible to increase the track spacing which has the potential advantage of allowing a faster work rate. To maintain the correct VAR and dose, either the sprayer forward speed must be decreased or the flow rate must be increased. In order to achieve the advantage of a faster work rate from the wider track spacing, the flow rate should be increased, if this is possible, rather than decreasing the forward speed.

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FAQ number 7 (see p. 82 for answers)

How can the track spacing and forward speed be measured reasonably accurately in the field?

Summary of calibration calculations

If you have been given a new insecticide to apply against Desert Locusts, or you need to make changes to the application parameters, the calibration calculations are a three-step process:

***Step 1*. Find the dose (g a.i./ha).** Read the pesticide label to find the manufacturers application recommendations for locusts. If this is given as a dose (g a.i./ha) go to Step 2. If it is given as a volume application rate (l/ha) go straight to Step 3. If there is no dose recommendation on the label, identify the insecticide active ingredient you are using and consult the FAO list of recommended doses (see Appendix 3.1) or other sources to determine the recommended dose for locusts in g a.i./ha.

***Step 2*. Convert the dose to a volume application rate (l/ha).** Read the insecticide formulation concentration in g a.i./l (often expressed as a percentage of weight to volume (%w/v) from the insecticide label and use Formula 1 on p.37 to calculate the volume application rate (VAR) in l/ha.

***Step 3*. Calculate the required flow rate (l/min).** Use Formula 2 on p. 41 to calculate the flow rate required to achieve this volume application rate (using realistic figures for track spacing and forward speed).

An example

For example, if you are controlling hopper bands with a vehicle-mounted sprayer using the insecticide bendiocarb as a 20 percent w/v (200 g a.i./l) formulation, travelling at 4.8 km/h and using a 25 m track spacing, the flow rate can be calculated using Formula 2. It has already been calculated that the required VAR to apply the recommended dose of bendiocarb 200 g a.i./ha formulation is 0.5 l/ha. Use Formula 2 opposite to get:

$$\text{Flow rate (l/min)} = \frac{0.5 \text{ l/ha} \times 4.8 \text{ km/h} \times 25 \text{ m}}{600} = 0.1 \text{ l/min}$$

Tip: if the wrong units are used, the formulae will give the wrong answer and the wrong dose will be applied. Be sure to check the units and convert them if necessary to the units in the formulae above. See Appendix 5.5 for conversion factors for common units.

How to decide what track spacing to use (full coverage spraying)

The track spacing is determined by the type of sprayer and the wind conditions during spraying. Track spacing must be large enough to allow target areas to be sprayed quickly, but not too large otherwise the insecticide will not cover the area between the spray passes evenly enough. Choose a track spacing according to the manufacturer's literature, the wind conditions and your experience of the sprayer. Typical track spacings are 10 m for handheld spinning disc sprayers, 30 m for vehicle-mounted drift sprayers (or 50 m for vehicle-mounted airblast sprayers) and 100 m for aircraft. Appendix 5.3 gives more detail on recommended track spacings. Appendix 2.2 describes the measurement of pace length so that field staff can measure track spacings reasonably accurately by counting their steps.

How to decide what sprayer speed to use

The forward speed is mainly determined by the limitations of the sprayer platform, i.e. the speed a person can comfortably walk (around 4 km/h), or the speed a vehicle can safely drive over rough ground (around 7 km/h), or the aircraft's normal flying speed (between 140 and 200 km/h). You should check the speed of the sprayer using a marked-out distance and a stopwatch (see Appendix 2.3 for details) and use that in the calculations. For aircraft, consult the pilot to check the normal airspeed for spraying.

How to decide what flow rate to use

The flow rate is usually the easiest of these three factors to adjust, and it must be set so that the correct VAR (and therefore dose) is applied when using your chosen track spacing and forward speed. Formula 2 is used to determine what the correct flow rate should be.

$$\textbf{Flow rate (l/min)} = \frac{\textbf{VAR (l/ha) x speed (km/h) x track (m)}}{\textbf{600}} \qquad \textit{Formula 2}$$

Tips: don't forget that if you are using an aircraft with two or more atomisers, the calculated flow rate should be divided by the number of atomizers to give the flow rate for each atomizer.

Formula 2 can be rearranged if any of the other variables need to be calculated, e.g. if flow rate and speed cannot be altered, the track spacing to use can be calculated:

$$\text{Track spacing (m)} = \frac{\text{flow rate (l/min)} \times 600}{\text{speed (km/h)} \times \text{VAR (l/ha)}}$$

Flow rate should be checked and adjusted if necessary:

- when a new sprayer is being used
- when a new insecticide is being used
- at the beginning of every day (except aircraft with flow meters that can be checked every week or so)
- if the spray cloud looks denser or less visible than usual
- if results are poor or if more insecticide than expected is being used

Tips:

- ***the manufacturer's manual should be consulted before setting flow rates for the first time. It usually gives calibration information that provides a starting-point for the flow rate calibration. It is possible to get a rough estimate of flow rate using diesel fuel or water, but remember that the flow rate must be measured with the insecticide itself because other liquids may flow more quickly or more slowly. Measure it at least three times to make sure there have been no errors.***
- ***a running check can be kept on flow rate (especially in the case of aircraft) by recording the time spent spraying and the amount of insecticide being used. If the amount of insecticide seems too great, the flow rate should be measured and reset if necessary.***
- ***when measuring flow rate from an aircraft fitted with an electric pesticide pump, have the aircraft engine running so that the correct voltage is being delivered to the pump. Make sure that pesticide is collected from all atomizers – the flow rate may be different from each and if any are switched off, this may affect the flow rate of the others. Thin plastic bags are useful to fasten over the atomizers to prevent the pesticide squirting outside the collecting bucket – a hole should be cut in the bottom of each bag to allow the emitted pesticide to flow out in a controlled manner.***
- ***equipment required for setting flow rate of ULV sprayers: Notebook, pen, stopwatch or watch with a second hand, measuring cylinder (100 ml, 500 ml or 2 litre depending on the type of sprayer), bucket, protective clothing, soap and water, sprayer, plastic bags to put over aircraft atomizers, insecticide with label.***

SPRAYER FLOW RATE

After calculating the flow rate required to apply the correct VAR, which will deliver the recommended dose, the flow rate should be set. This must be done with the insecticide itself since water, diesel fuel and even different pesticides have different viscosities (a measure of the thickness of the liquid) and will all have different flow rates. The general principles of measuring flow rate are the same for all types of sprayer. However, aircraft may either be easier (if they have an electronic flow meter) or more difficult (if they have a windmill driven pesticide pump – see Appendix 2.5 for technique).

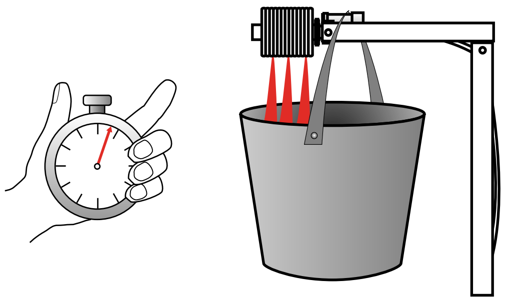
Some sprayers work in a way that allows the operator to collect and measure the liquid emitted over a given time, i.e. the collection technique. This can be used, for example, for a spinning disc sprayer when the disc is stationary. It is more difficult with some other sprayers, e.g. the exhaust nozzle sprayer, since the spray comes out together with the airblast and cannot easily be collected. In these cases, the easiest method is to measure the amount missing from the tank after a given time, i.e. the loss technique – see the next page for both techniques. Many spray aircraft are fitted with windmill-driven pumps that only reach operating pressure when in flight so the only option for flow rate calibration (and checking flow meter readings) is the loss technique. See Appendix 2.5 for practical details on using the loss technique for aircraft flow rate calibration.

Procedures for adjusting the flow rate vary from sprayer to sprayer. Adjustments may be made by fitting a different restrictor nozzle, changing variable restrictor setting, altering a needle valve setting or changing the insecticide pump pressure. Consult the manufacturer's manuals for exact details.

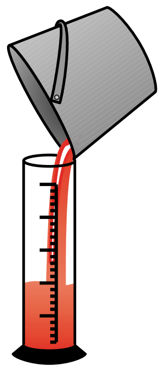
Tip: on some sprayers, the flow rate can only be adjusted in steps, e.g. by fitting one of a series of restrictors. In this case the restrictor that gives a flow rate nearest to the calculated flow rate should be selected and then if the actual flow rate is different from the desired flow rate, Formula 2 should be used to recalculate a modified track spacing or forward speed to produce the required VAR and the recommended dose.

Figure 17. The collection technique for flow rate measurement.

1. Allow pesticide to flow from the sprayer for one minute



2. Measure the number of litres emitted and collected



> ***Tips:***
>
> - ***if the wrong units are used, the formula will give the wrong answer and the wrong dose will be applied. Be sure to check the units and convert them if necessary to the units in the formula 3 above. Conversion factors are given in the Appendix 5.5.***
> - ***it is possible to make a dipstick for some sprayers, e.g. the ENS. Marks can be made on the dipstick to indicate litres of spray liquid in the tank.***

The collection technique for flow rate measurement

(for use when the spray liquid can be collected easily as it is emitted)

Step 1. Put on protective clothing, including gloves, fill the sprayer and position it to deliver insecticide into a measuring cylinder (via a funnel), or into a bucket.

Step 2. Allow the insecticide to flow from the sprayer into the container for a measured number of minutes (M) – one minute is usually sufficient.

Step 3. Use the measuring cylinder to measure the number of litres emitted and collected (E).

Step 4. Calculate the flow rate (F) in l/min by using Formula 3 below:

$$\mathbf{F\ (l/min)} = \frac{\mathbf{E\ (l)}}{\mathbf{M\ (mins)}}$$ ***Formula 3***

Step 5. Adjust the flow rate to bring it closer to the required value calculated previously and check it again. Keep altering and checking until the required flow rate has been achieved.

Step 6. When the required flow rate has been achieved, recheck two more times to ensure that it is correct.

The loss technique for flow rate measurement

(for use when the spray liquid cannot be collected easily as it is emitted)

Step 1. Fill the sprayer up to a known level with insecticide (either completely full or to a marked level) and spray over the target area using your normal spraying technique for a measured number of minutes (M) – one minute is usually sufficient.

Step 2. Use a measuring cylinder to measure the amount of insecticide required to refill the sprayer back to its original level. This will give the volume in litres emitted (E).

Step 3. Use Formula 3 to calculate the flow rate and adjust as above to the required value calculated previously.

Step 4. When the required flow rate has been achieved, recheck two more times to ensure that it is correct.

See Appendix 2.5 for specific instructions on aircraft flow rate calibration using the loss technique.

Advantages and disadvantages of different spray strategies

Advantages	Disadvantages
Single hopper bands (spot treatment)	
● efficient with insecticide	● difficult and time-consuming to find and treat all the bands so control is slow
Blocks of hopper bands	
● easier because individual bands do not have to be found	● less efficient with insecticide since a lot of uninfested land is sprayed ● greater environmental impact
Barrier spraying of hopper bands	
● efficiency/environmental benefits since not all of the land is sprayed ● easier since the individual bands do not have to be found	● requires a product that remains active for some weeks on vegetation. Further research is required on best doses, barrier spacings and barrier widths
Settled swarms	
● they are a good spray target with many locusts in a small area	● difficult to find early in morning ● short period for spraying in the morning before swarm takes off
Flying swarms	
● efficient pick-up of insecticide ● spray period greatly extended	● locusts may block the engine and windscreen unless the aircraft is locust-proofed ● very dispersed swarms cannot be sprayed efficiently

Tip: gregarious locusts do not always form a good target. Sometimes hopper bands are very spread out, particularly when there is a lot of green vegetation, and when swarms begin laying eggs, they tend to disperse. The only thing to do in these cases is to try to delimit blocks containing areas of heavier infestation to try to kill a significant proportion of the locusts without wasting too much pesticide.

ULV SPRAY STRATEGIES

There are several different types of ULV spray strategy to deal with 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, but some strategies spray only part of the area (see Barrier spraying below).

Spraying single hopper bands (spot treatment)

This involves finding and spraying individual hopper bands. Portable or vehicle-mounted sprayers can be used, but a lot of insecticide will be wasted with aircraft since they cannot be used efficiently for targets smaller than 0.25 km^2 (25 ha).

Spraying blocks of hopper bands

This involves marking a block of land which has a relatively high proportion of its surface area covered by bands, say up to four percent. The whole block is then sprayed by vehicle or aircraft. This is wasteful of insecticide and has a greater potential environmental impact, but may be the only method fast enough to treat an area containing many bands before they fledge, i.e. become adults with wings.

Barrier spraying to control hopper bands

This means spraying a persistent insecticide in strips with large unsprayed areas in between. As the bands in the infested area move, they eventually encounter these sprayed strips and eat the sprayed vegetation. Barriers can be sprayed with portable, vehicle-mounted or aerial equipment (see p. 63). Lattices or grids of sprayed vegetation have also been used in the past and research is continuing on these and other methods of spraying only part of an infested area.

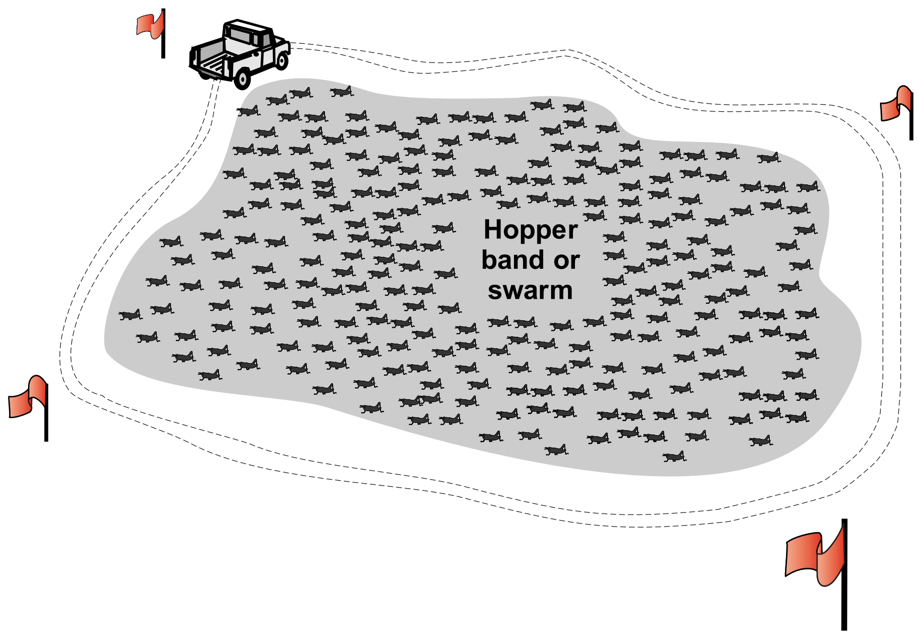
Spraying settled swarms

This means spraying swarms that are roosting on vegetation, usually either in the morning before take-off or in the late afternoon when the swarms have settled again. Settled swarms are usually sprayed by aircraft but vehicle-mounted airblast sprayers are sometimes used, occasionally at night. 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.

Spraying flying swarms

Swarms are sprayed from aircraft while they are either milling (some of them making short flights around the roost site in the morning or evening) or in full flight (see p. 67).

Figure 18. Driving around and marking a large hopper band or swarm.



Tip: when a hopper band is found, there will be others in the area. If no hopper bands are found, it does not mean there are none in the area – they may simply not have been found.

Tip: finding and treating all the hopper bands in a large infestation are difficult tasks requiring many teams and long hours. The potentially infested area should be divided into cells for each ground team to search, and a systematic search method should be used as in Fig. 20. A hopper band will probably not be seen if the vehicle is more than 50 m away from it so the parallel search passes should not be more than 100 m from each other.

HOW TO FIND AND DELIMIT THE TARGET

Finding individual targets – bands and swarms

The mechanism for finding locust targets will vary from country to country (see the Survey guideline). 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 will go to that area in vehicles 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, but aerial spraying without ground support should be avoided if possible. It is always better to have a ground team to direct the aircraft and check on application and efficacy, i.e. how many of the locusts are killed (see p. 71).

Searching for individual bands or settled swarms can be carried out by driving through the infested area systematically looking for vegetation, locusts and for signs, such as birds feeding on them. Information from local 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 but a helicopter can more easily fly lower and slower – if a possible band is spotted, it can go back or land for a closer look.

When a band or swarm is located, the search team can either mark the location of the target for control teams/aircraft that will arrive later or, if it is equipped with spraying equipment, it can carry immediately out the control itself. 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 handheld global positioning system (GPS) unit if one is available (see Appendix 1.4). These coordinates can be given to ground spray teams also equipped with GPS, or relayed to spray aircraft pilots (if there is radio communication and GPS on board) to guide them to the targets.

Delimiting and marking individual targets – bands and swarms

Before spraying starts on large bands or swarms, the control team should delimit the target. This means driving or walking around it and, if possible, placing flags, people or vehicles at the corners of a spray area that is big enough to cover the target. If the target is large (more than 1 km^2) and it is planned to spray it by aircraft, GPS coordinates can be recorded for the four corners for relaying to the pilot and/or smoky fires can be lit at each point. The smoke also helps the pilot to judge the wind direction, although the aircraft may be fitted with its own smoke generators for this purpose. The spray area should extend some metres beyond the edges of bands to be sure of covering them. If a band is moving, extend the spray area even further (20-40 m) in the direction of movement so that the locusts move into sprayed vegetation.

Figure 19. Driving two lines through a block of bands or a scattered swarm to delimit the target.

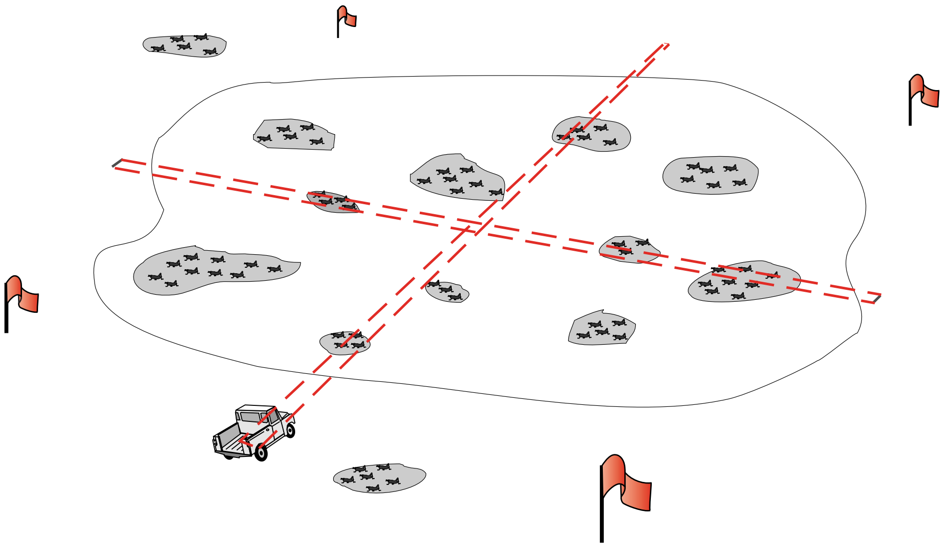
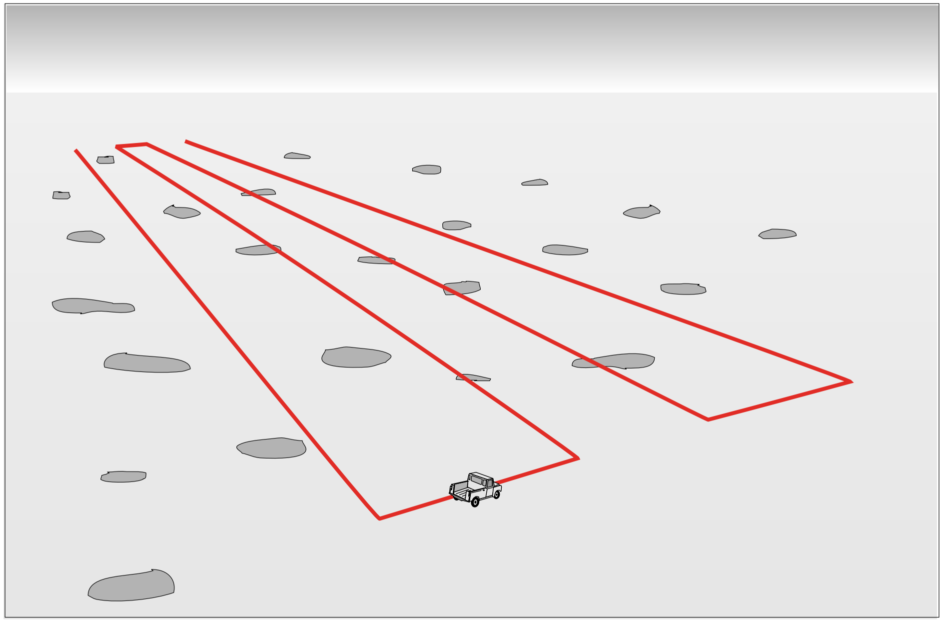


Figure 20. Driving systematically through an infested area to locate bands or swarms and to delimit the infested area.



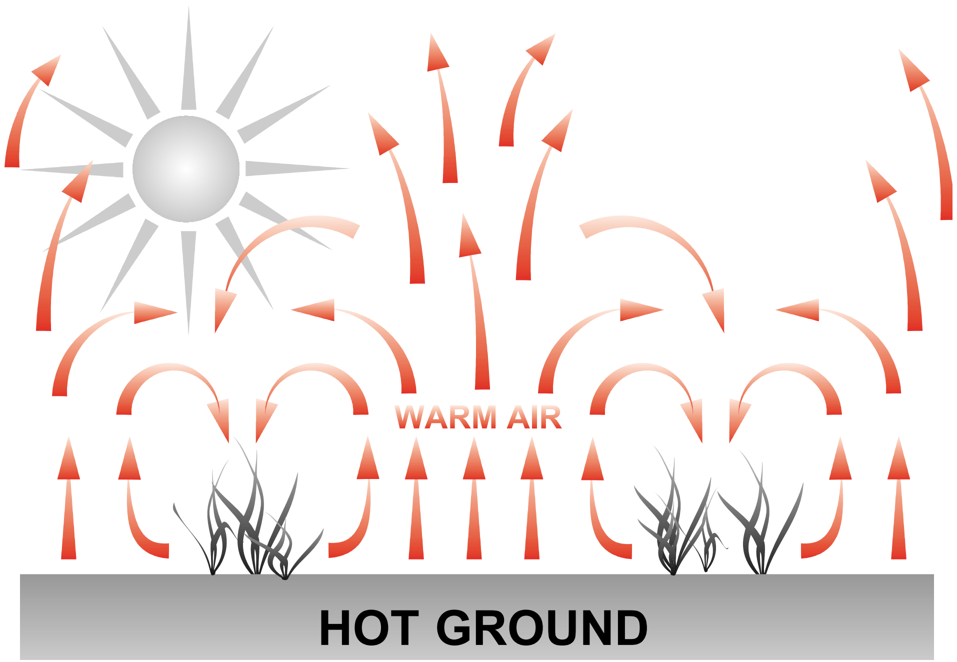
Delimiting a block of bands or a scattered swarm

Marking the extent of a block of bands or scattered swarm is even more difficult than marking individual targets. There is not usually time to carry out an accurate search from a vehicle to find all the locust targets, so the technique often used is to drive a transect through the suspected infested area in one direction to determine 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 infested area extends to either side. These lines form a cross in the middle of a rectangular or square block (see Fig. 19). If the block is not too big, the vehicle then drives around the edge of the block to mark the corners, and the size is adjusted if necessary to include locusts which are outside the original rectangle. Some locusts will often still lie outside such a block and, when locusts are dispersed or in small patches, decisions on delimitation will be highly subjective and often inaccurate. The method depends not only on judgement but also on guesswork and luck.

If the area of bands or swarms is very large, a more systematic method is necessary to demarcate the spray block. Drive a pattern similar to Fig. 20 through the suspected infested area. The 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 about 200 m can be used. Bands are difficult to see at more than 50 m distance so a spacing of about 100 m should be used. Since there will be no markers to guide the vehicle, drive on compass bearing, i.e. try to keep to a certain number of degrees on the compass then for the opposite direction, drive at 180 degrees to the original line (see Appendix 1.3 for instructions on how to use a compass). A GPS can be used to navigate instead of a compass and can be very useful for marking the corners of the large spray block (see Appendix 1.4 for instructions on GPS use).

Tip: these methods are not very effective and delimiting large targets is often inaccurate. They may seem to be effective to those who are using them, but this is sometimes because the undetected locusts are, by definition, not being found.

Figure 21. Convection (rising columns of warm air) occurs in hot, sunny weather if the wind is light.



When NOT to spray

Weather	Action	Reason
Wind less than 2 m/s	do not spray	narrow swath, poor efficacy and operator may be contaminated
Wind more than 10 m/s	do not spray	swath width will be very wide and deposition difficult to predict
Sun is very high	do not spray	convection may take the spray out of the target area
Rain is falling or will fall soon	do not spray	insecticide will be washed off the target

Tip: humidity is not usually important to ULV spraying as it will not influence the evaporation rate of oil-based droplets.

WEATHER CONDITIONS FOR ULV SPRAYING

When to spray

The best time for spraying is usually in the morning between 0800 and 1100 hours and in the afternoon after 1600 hours. Effective spraying may be possible before 0800 hours if the wind is strong enough. It may also be possible to spray effectively between 1100 and 1600 hours if it is either cloudy and relatively cool (less than about 30°C) or if there is a steady wind over 4 m/s that will tend to prevent convection.

When not to spray

Three weather factors are important for ULV spraying:

Wind

Never spray when there is no wind because the spray will not be spread properly over the swath and the operator is likely to be contaminated because the spray is not being carried away from him/her. There should be a steady wind of at least 2 m/s measured at a height of 2 m (a distinct breeze felt on the face). Do not spray when the wind is more than 10 m/s (dust and leaves are blown around) since it is not easy to predict where the spray will deposit.

Sunshine

Never spray when there is strong convection. Convection occurs when the sun rises high in the sky and heats up the ground. The hot ground warms up the air near to it, which then rises and may carry spray droplets out of the target area (see Fig. 21). Convection usually occurs on hot afternoons but may also occur in the late morning, especially if there is very little wind. Convection cannot usually be seen (except when strong updrafts pick up dust or if spray aircraft have smoke generators) but it can be detected by taking notice of wind strength and direction – frequent changes in wind strength and wind direction are a sure sign that convection is occurring.

Rain

Never spray if rain is falling or seems likely to fall soon, because the rain may wash off some of the insecticide from the vegetation.

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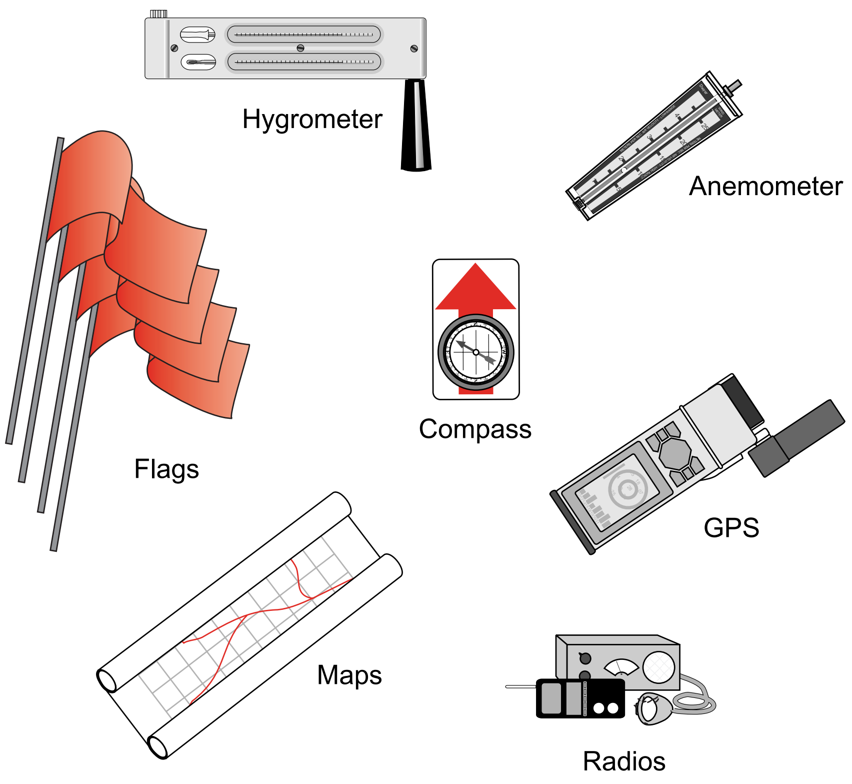
FAQ number 8 (see p. 82 for answers)

What can the spray team do if they must control locusts urgently but weather conditions are not suitable for ULV spraying?

Figure 22. Some field equipment for Locust Field Officers.



Tip: field equipment is essential for field officers. It allows them to do their job properly and builds their confidence and others' confidence in them. Every effort should be made to equip field officers with these and other items of equipment (see a more comprehensive list on the following pages). The right equipment can help to make operations safer and more efficient with large savings in time and money.

HOW TO CONTROL LOCUSTS USING ULV SPRAYING

The Locust Field Officer in charge of the control operation will be responsible for supervising the sprayer settings and the techniques used, whether the control is being carried out by farmers, hired helpers or Locust Unit staff. Even when spraying is being carried out from an aircraft, the Locust Field Officer should be in charge of its activities and should direct the pilot in the same way that he would direct a vehicle driver or portable sprayer operator. He/she should take part in the calibration process at the airstrip and instruct the pilot on suitable spray conditions, on spraying height and on flight pattern. The only exception to this is when the safety of the pilot or aircraft is concerned, in which case the pilot's judgement must be final.

Field equipment

The Locust Field Officers will be able to do a better job if they have various items of field equipment – this will help to make control operations safer and more efficient (see Fig. 22). Procedures for using some of these items of equipment are described in Appendix 1.

Meteorological equipment

- anemometers to measure wind speed. These can either be whirling cup devices or pith ball type
- a whirling hygrometer to measure air temperature – humidity is not so important, but the whirling hygrometer will give a more accurate measure of air temperature than a stationary thermometer

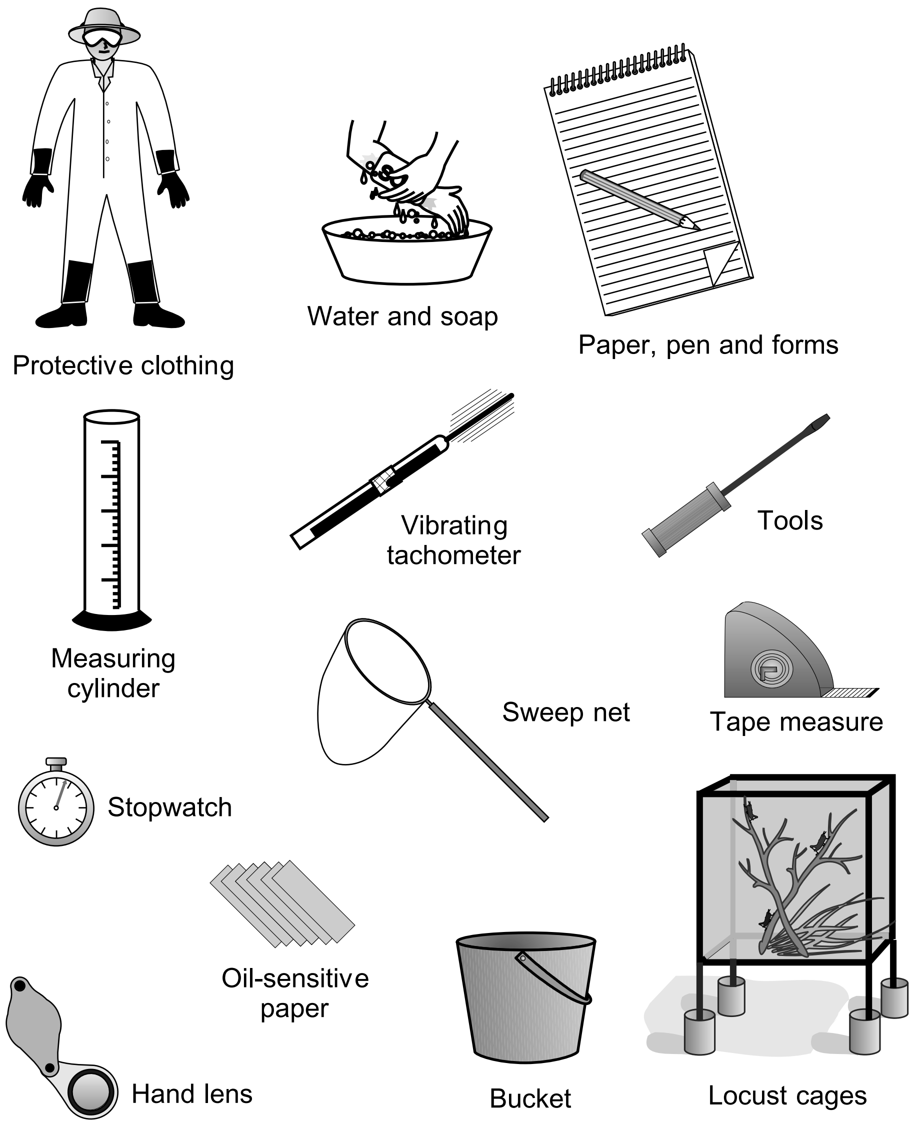
Navigation equipment

- compass with twisting bezel for navigation and checking wind direction
- maps for navigation
- GPS for finding targets and marking locations

Communication equipment

- short range radios – VHF or UHF walkie-talkie radios for short-range and communication with aircraft
- long-range radios in vehicles and at bases – HF or SSB
- flags for guiding aircraft – these should be large (minimum 1 m x 1 m) of red, orange or yellow (for use against sand or bare soil) or white cloth (for use against green vegetation) on long poles (2-3 m long)
- signalling mirrors for guiding aircraft - there are specially designed so that the sunlight can be reflected accurately towards an aircraft

Figure 23. Some of the equipment required for calibration and spraying.



Tip: it is useful if each officer is issued with a field bag to hold the full range of equipment appropriate to their tasks.

Calibration/spraying equipment

- protective clothing consisting of cotton coverall, hat, nitrile rubber gloves, goggles or face shield, rubber boots
- water and soap for washing
- clipboard, paper and pen and spray monitoring forms if available
- vibrating tachometer to measure rotational speed of rotary atomizers
- oil-sensitive paper to sample ULV spray droplets
- hand lens (x10) to examine number/approximate size of ULV droplets
- plastic measuring cylinder to measure volumes of pesticide
- bucket to collect pesticide
- stop watch or watch with second hand for timing flow rates
- tool kit – pliers, screwdrivers (cross and flat head), adjustable spanner
- 50 m tape measure to calibrate pace length and sprayer forward speed
- sweep net to collect locusts for examination and caging
- cages for mortality assessment

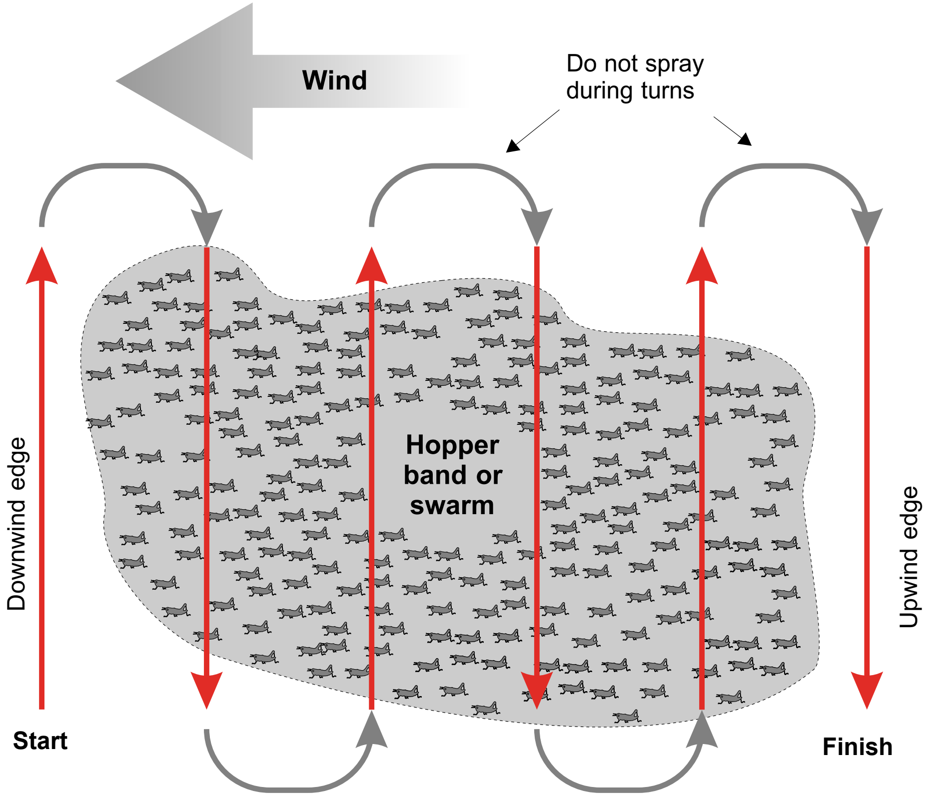
Tips:

- ***this equipment is an investment which can help to save many thousands of dollars of pesticide and prevent risks to operator and environment***
- ***coveralls should be cotton (rather than plastic or other waterproof material) because it allows sweat to evaporate and keep the operator cool. The disadvantage is that cotton absorbs liquids. If the coverall becomes wet with pesticide, it must be taken off and washed, and all protective clothing should be washed at the end of each spray day***
- ***always put the coverall legs outside the boots and the gloves outside the coverall arms to prevent spills coming into contact with the hands and feet***

!

Gloves should be nitrile rubber because ULV pesticides pass through natural rubber gloves – even thick ones. They absorb pesticides and act as an effective compress against the operator's skin.

Figure 24. Spraying a hopper band or a swarm (full coverage).



Tip: a method of track marking, i.e. guidance to the ends of the spray passes, is important in order to achieve accurate application. It is very difficult for any sprayer operator, whether he/she is a portable sprayer operator, vehicle driver or aircraft pilot, to estimate the correct track spacing and spraying direction, especially on long spray runs.

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Before spraying is carried out, the local community in the area must be informed so that they can move livestock, beehives and people out of the area likely to sprayed.

How to spray ground targets (on the soil or on vegetation)

The basic procedure for full coverage spraying (also called blanket spraying) is the same for all ground targets – bands, blocks of bands or settled swarms. The procedures and principles are also the same whether the sprayer is portable, vehicle or aerial, although some practical details may differ, e.g. aircraft filling, calibration and cleaning will be done at the airstrip.

Step 1. Delimit and mark the target area. This means finding and marking the corners of the block to be sprayed (see p. 48-51).

Step 2. Check weather conditions are suitable, i.e. steady wind and no convection (see p. 52-53)

Step 3. Check wind direction and take all spraying equipment and personnel to the downwind edge of the area to be sprayed.

Step 4. Put on protective clothing and read the insecticide label.

Step 5. Fill the sprayer (using filters, funnels and/or pumps) and calibrate the sprayer for droplet size, emission height and dose (see p. 34-45).

Step 6. After moving all other non-spraying personnel, vehicles and equipment to the upwind side of the target area so that they will not be contaminated with insecticide, start spraying across the direction of the wind (at right angles to it), making sure spray is carried away from you. If there are flagmen or some other means of measuring and following the exact track spacing, the application will be more accurate and efficient (see Appendix 2.6 for aircraft flag marking procedure).

Step 7. When you reach the other side of the spray area, stop spraying and move upwind by the distance of one track spacing. Spray the new pass in the opposite direction to the first pass. Move upwind again, and continue in this way until the whole area is sprayed (see Fig. 24). Make two spray passes at the upwind edge to compensate for underdosing there, or make an extra spray pass upwind of the target area.

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FAQ number 9 (see p. 82 for answers)

What tactics can be used if hopper bands are under tall, dense vegetation, such as a millet crop, or on the downwind side of dense bushes?

Tips:

- ***it is very important to spray at right angles to the wind direction. If the operator sprays up and down the wind direction, the result will be a large overdose on a very narrow strip of the target area, and possible operator poisoning during downwind spraying***
- ***do not expect to see the spray on locusts or vegetation after ULV spraying. The droplets are very small and if you can see them, or you can see surfaces wet with spray, they are probably too large or too many***
- ***do not expect locusts to die immediately. If they do, you have probably applied more insecticide than necessary (the exception is pyrethroids which can give a knockdown in a few minutes)***
- ***for settled and milling locust swarms, better control should theoretically be obtained by spraying the swarm twice using half the flow rate for hopper band treatment to allow locusts to change positions between spray passes. This will increase the chances of the pesticide reaching all locusts – those which were protected by vegetation or other locusts during the first spray pass may have moved by the time the second spray pass is carried out. However, aircraft costs will be higher as a result of the additional flying hours required and time constraints may make this impractical***

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FAQ number 10 (see p. 82 for answers)

If there are no aircraft sprayers available, how can locusts in tall trees be sprayed using ground-based sprayers?

Step 8. If the wind drops or becomes very strong (more than 10 m/s), stop spraying and wait for the right conditions. If the wind direction changes by more than 45 degrees, stop spraying, go to the new downwind edge and start from Step 6 again, spraying the remaining unsprayed area.

Step 9. When spraying is finished, empty any remaining insecticide back into the insecticide container. Clean the sprayer by putting a small amount of diesel fuel or kerosene into the tank and spraying it off over the target area. Clean the outside of the sprayer using diesel fuel or kerosene on a cloth (see p. 81).

Step 10. Store unused insecticide and the sprayer in a safe place away from children, animals and food. Wash your body and protective clothing as soon as possible (see p. 81).

Step 11. Dispose of empty pesticide containers properly (see p. 81).

!

Never go downwind of a working ULV sprayer – you may be contaminated by the drifting spray.

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FAQ number 11 (see p. 82 for answers)

How can small patches of locusts be sprayed using ULV equipment?

Figure 25. Four operators spraying in formation without contamination.

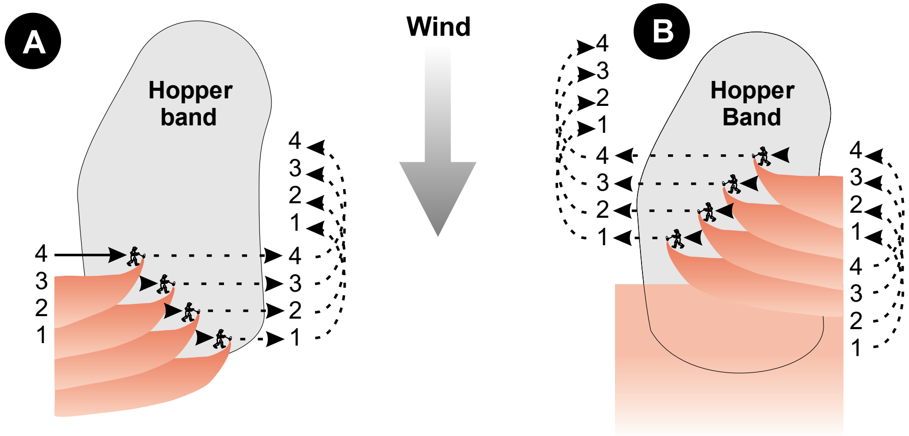
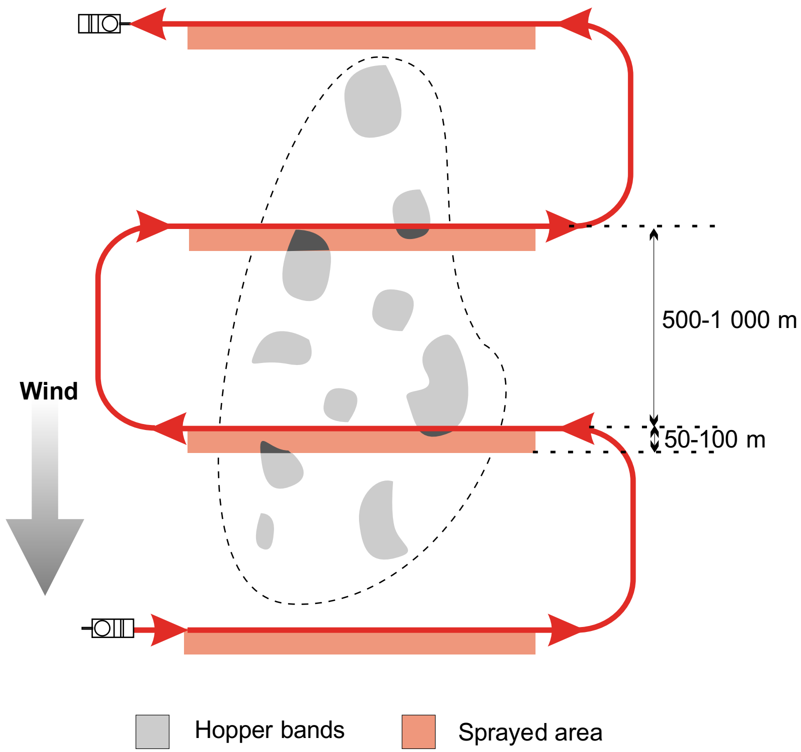


Figure 26. Barrier spraying a block of bands.



Special cases

Spraying in formation

If more than one sprayer is being used, for example if four operators are using handheld spinning discs to treat a band, they must move in a particular formation to avoid spraying one another. Each operator should be assigned a number. Operator 1 will always start spraying first and will always be at the downwind end of the formation. When operator 1 has moved the distance of about one track spacing into the block, operator 2 should start and when he/she has moved the distance of one track spacing, operator 3 should start, and so on (see Fig. 25A). When each operator reaches the other edge of the block, he/she should move quickly upwind to his/her new position to avoid being sprayed by the operator behind and upwind. When all operators are ready in their new positions, operator 1 should lead off again in the opposite direction across the block followed by the other operators (see Fig. 25B). One flagman on each side of the block to guide operator 1 is usually sufficient to ensure reasonably accurate track spacings.

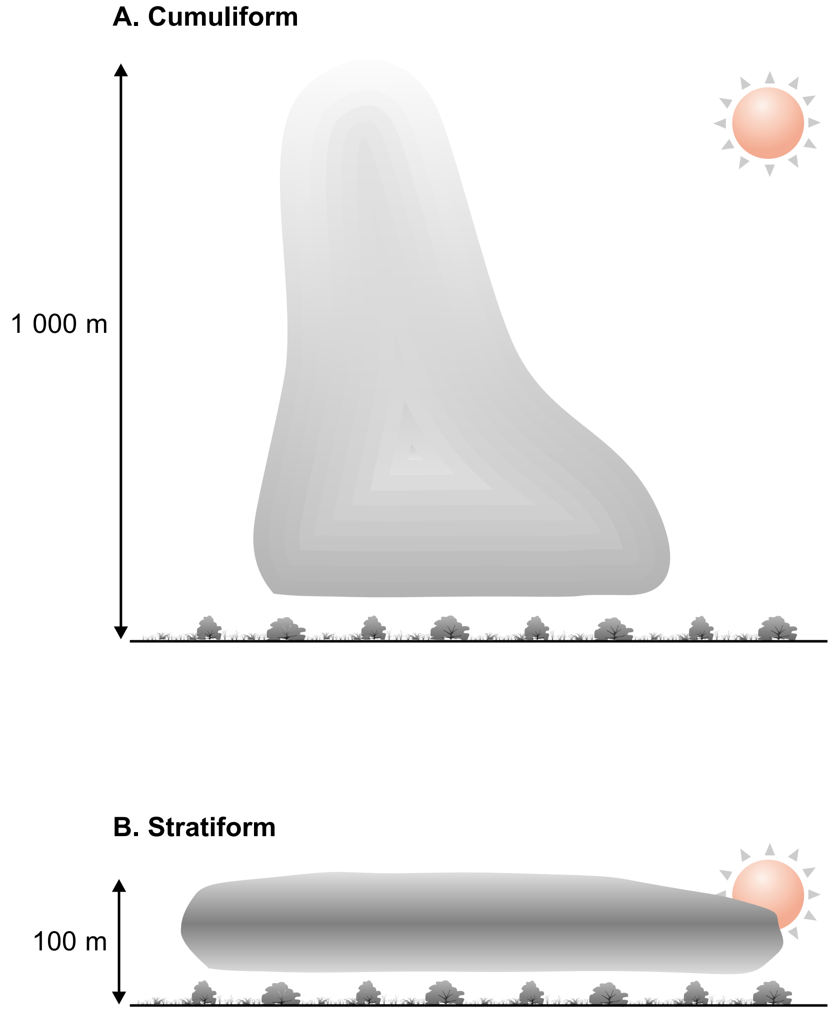
If two aircraft are spraying in formation, the principle is the same, with the downwind aircraft leading so that it is not contaminated by spray from the upwind aircraft.

Barrier spraying

The procedure for barrier spraying is the same as that for full coverage spraying, except that the operator(s) moves upwind a long way at the end of the cross wind spray passes to leave large unsprayed gaps between barriers (see Fig. 26). In this case, the target is the vegetation, but sprayer settings should be the same as for spraying locust targets. The width of the barriers, the distance between them and the dose within them are still being researched for a variety of new potential barrier products. However, recent trials indicate that spacings of up to 1 km are effective with IGRs and phenylpyrazoles. Other spray configurations are being researched, e.g. grids or lattices of sprayed vegetation and green patch spraying where only the areas with green vegetation are sprayed.

A 50 m wide barrier can be applied either by four handheld spinning disc sprayer operators working in formation, by two passive drift vehicle sprayers driving in formation, or by one airblast sprayer (see Fig. 25). If an aircraft is used to try to produce a 50 m wide barrier, it must fly quite low – about 5 m height – to make the swath width as narrow as possible, but it will probably still be wider than 50 m under normal spraying conditions. However, successful barrier spraying has been carried out on other species of locust using flying heights up to 20 m that will inevitably produce a wider swath of 200 m or over. It is not known whether a wider barrier with a lower dose will be as good as, or better than a narrow barrier with a higher dose for Desert Locust control, and if so, which products this would apply to – research is still being carried out.

Figure 27. The configuration of cumuliform (A) and stratiform (B) swarms.



Aerial spraying of flying swarms

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.

The flying swarms may be milling around the roost site or they may be in full flight either as stratiform swarms (low flying up to heights of 100 m) (see Fig 27b) or cumuliform swarms (flying up to heights of 1 000 m or more) (see Fig. 27a). Swarms are usually stratiform in the morning and late afternoon, and become cumuliform in the heat of the day when convection takes place from the hot ground. These flight patterns are not completely separate and swarms may take a form halfway between stratiform and cumuliform.

Spraying milling swarms

Spraying 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 locusts will rest 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, in theory, better control should be obtained by spraying the swarm twice, using half the flow rate for hopper band treatment, to allow locusts to change positions between runs. However, this will result in higher flying costs and there may not be sufficient time to treat the target twice before it moves. This technique has not been fully validated in the field for Desert Locust control.

Spraying swarms in full flight (air-to-air spraying)

The aim when spraying flying swarms is 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 should be much easier to spray low flying stratiform swarms (see Fig. 27B) than high flying cumuliform swarms (see Fig. 27A), but there is very little information on best practice for either. Air-to-air spraying is rarely carried out these days and techniques used in the past have not been well reported. The advice given on the next page is speculative and should be considered as a starting point for the development of effective techniques.

! **Air-to-air spraying has only been carried out in a few countries, mainly in Eastern Africa, and requires experienced pilots with aircraft that have been specially modified to prevent locusts blocking the engine air intakes, clogging the cooling systems and obscuring the windscreen.**

Figure 28. Spraying repeatedly upwind of a cumuliform swarm

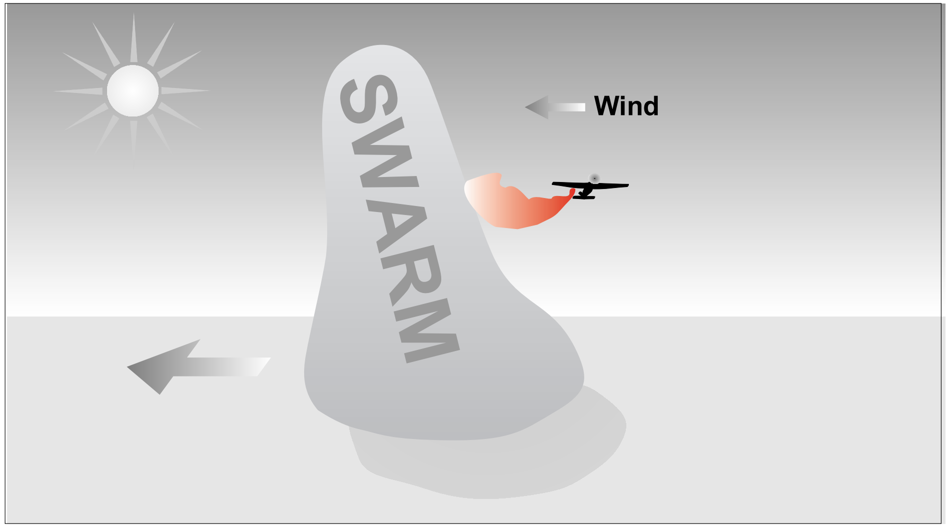
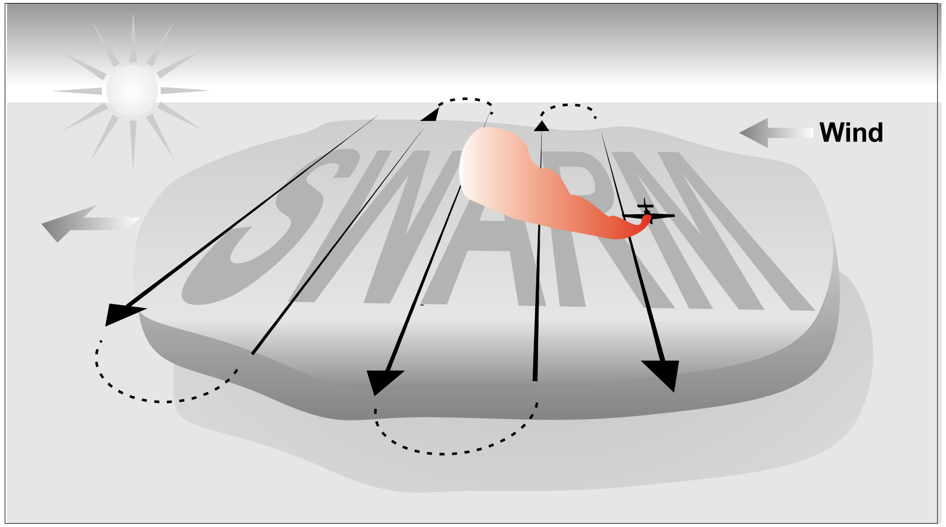


Figure 29. Spraying a stratiform swarm like a settled target



Tip: aerial spraying with helicopters is almost the same as with fixed-wing aircraft, except that helicopters are more manoeuvrable, can land without an airstrip and can be used in narrow valleys where it might be dangerous for fixed-wing aircraft. They are also very useful for survey. However, they are more expensive to operate and maintain, have a shorter range and are slower than fixed-wing aircraft so should only be used when really necessary.

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 that will fall slowly through the swarm so that they can be collected by the flying insects. However, 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 75-100 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 achieve better control, although aircraft costs will be higher. The spraying should start at the downwind edge (see Fig. 29) but, if the swarm is moving fast with the wind, the aircraft should reduce its track spacing accordingly. The accuracy of this will depend very much on the pilot and/or GPS equipment because flag marking will not be possible from the ground.

Spraying cumuliform swarms

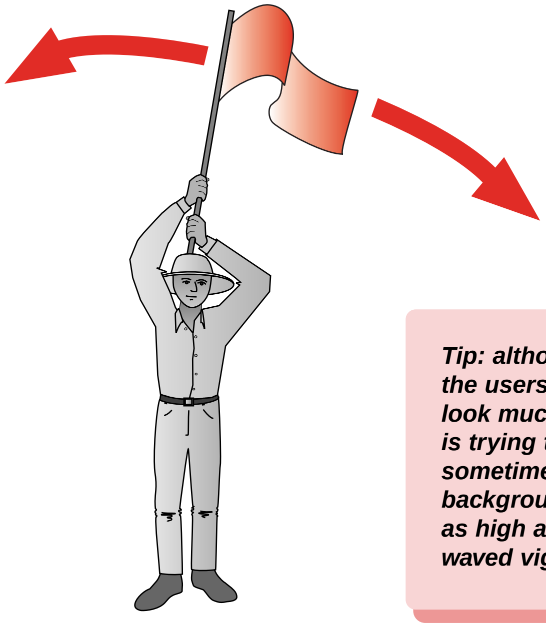
The concept of dose does not really apply to spraying cumuliform swarms – it is more like a space spray than a surface spray. The only advice available is to spray repeatedly just above the densest part of the swarm on the upwind side using half the emission rate for settled locust treatment (see Fig. 28). Continue spraying until the swarm disappears. The spray should remain within the swarm for a long time and the movement of the locusts should bring them into the spray cloud.

The same-sized droplets as used for treating stratiform swarms are 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 moderately fast-acting insecticides, such as organophosphates and carbamates, lethally dosed locusts should fall to the ground within about half an hour, and all those that fall should die. Synthetic pyrethroids have a rapid knockdown action so locusts should start falling out of the swarm very quickly. However, if they fall out before they have acquired a lethal dose, i.e. sufficient insecticide to kill them, there is a risk that they may recover and fly off later. This concern has not been confirmed by field observation or trials.

There is very little documented information about spraying flying Desert Locust swarms, either from trials or actual control operations. FAO would be interested to hear how successful these techniques are, and to be informed of any other methods which give good results.

Figure 30. Flagman signalling vigorously to an aircraft.



Tip: although flags look large to the users on the ground, they look much smaller to a pilot who is trying to see them from the air, sometimes against a confusing background. They should be held as high as possible in the air and waved vigorously.

Tip: when two flagmen are being used at each side of a spray block to guide an aircraft, only one flag at each side should be up at any one time. It is sometimes difficult for the pilot to judge which flag to go towards if he/she sees more than two flags being held in the air.

! **Whether guiding portable, vehicle or aircraft sprayers, the flagman must always move upwind a few seconds before the sprayer reaches him/her, and remain upwind of the sprayer at all times, otherwise he/she will be contaminated by the spray.**

Marking track spacings for settled targets

ULV spraying will give a reasonably uniform deposition even if track spacings are not very accurate. For example, if an aircraft that is supposed to be using a track spacing of 100 m makes one spacing of 110 m, then a spacing of 90 m, the fact that the swaths overlap means that the deposition uniformity will still be acceptable. However, if the pilot consistently uses a 90 m track spacing, then the result will be an overdose of more than 10 percent – a considerable financial waste and unnecessary environmental risk. It is the undesirable consequences of these consistent errors that make it worthwhile to have some system of track marking or GPS track guidance.

Ground spraying

For ground spraying with portable and vehicle-mounted sprayers, one person with a large flag is sufficient at each side of the spray block. They should calibrate their pace (see Appendix 2.2) so that they know how many paces to use for 10 m or for 30 m, and they should pace out the correct track spacing for the end of every spray pass. Even if there are two or more sprayers working in formation (see Fig. 25 on p. 62), one flagman at each side of the block should be sufficient. The flagman guides the leading sprayer who is always furthest downwind and the other sprayers estimate their distance upwind from him/her. GPS track guidance is becoming available for vehicle-mounted sprayers that will improve track spacing accuracy considerably.

Aerial spraying

Flag marking for aircraft is more difficult because the track spacings are larger and the aircraft moves very quickly. It is not usually possible for a single flagman to measure out 100 m to the next spray pass in the time it takes for the aircraft to turn at the edge of the block. It is easier to have two flagmen at each edge, and for the upwind one to be ready in position by the time the aircraft begins its turn. Special mirrors with sights can be used instead of flags – these reflect the sunlight towards the aircraft and the pilot can see a bright flash from a great distance. Vehicles can also be used as markers if they are available. The vehicle odometer can be used to measure the track spacings, but this should be checked for accuracy against a measured 100 m line.

Aircraft-mounted GPS coupled with track guidance equipment such as a light bar are increasingly used to improve accuracy and monitoring of operations. With the right signal correction facility, the GPS can guide the pilot on track spacings to an accuracy of a few metres, and can record and download for later review exactly where the pilot flew, at what height, where he/she sprayed, what atomizer speed was used, etc. If an additional flow control is installed, the system can automatically switch the sprayer on and off at the end of each spray pass and can adjust the flow rate to compensate for varying ground speed due to gradients or wind shifts. It is also possible to enter the map coordinates of ecologically sensitive areas so that the sprayer switches off automatically in time to avoid spraying the area (including a buffer zone around the area to allow for drifting spray).

Summary of the most important points to record when monitoring spray operations:

- area infested
- area sprayed
- type of sprayer and settings
- volume and type of pesticide used
- efficacy

Tip: if efficacy is poor, the Locust Field Officer can check that droplets are depositing in the target area by mounting oil-sensitive papers on vertical sticks (75 cm long) at intervals across the block. The officer should first check that the paper is sensitive to the pesticide – there are some formulations which leave only a very faint mark, rather than the clear black mark required to detect small droplets on the papers. Some formulations give a clear black mark initially, but it fades rapidly. Oil-sensitive papers should therefore be analysed as soon as possible after exposure to the spray.

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FAQ number 12 (see p. 82 for answers)

How many droplets should be found on oil-sensitive paper in order to give good locust mortality?

MONITORING CONTROL OPERATIONS

Monitoring is very important in order to document the activities and to allow later analysis of the successes and failures of any campaign. Lessons can always be learned which will help to improve safety or efficiency in the future but, very often, there is very little clear information of exactly what happened in the heat of a locust campaign. There are many things to record such as fuel usage and staff time spent on control, but this guideline will only deal with recording control operations and their efficacy.

Spray monitoring

Every organization will have different requirements, but the *FAO Spray Monitoring Form* covers the most important pieces of information (see Appendix 4.2). Technicians and Locust Field Officers can use forms like this to record the details of every control operation. On the *FAO Spray Monitoring Form*, a new column is used for every location sprayed, whether it is a band, a block of bands or a swarm, regardless of spray platform – handheld, backpack, vehicle-mounted or aircraft. The form should be completed with the *FAO Desert Locust Survey and Control Form* (in order to include details on the location, rainfall, ecology and locusts) and both forms should be returned to the National Locust Unit headqurateers on a regular basis for review by the Head of the Locust Unit. Any problems which turn up, e.g. lack of protective clothing, overdosing, poor efficacy, non-target effects, can be addressed quickly for subsequent control operations.

Tip: if control teams are using a pesticide which should be applied at 1 litre/ha and the record of area sprayed is exactly the same as the number of litres used, there is a suspicion that they have derived the area treated from the volume of pesticide used. This is unsatisfactory, and very often the actual area treated is much smaller, but a large overdose was applied. The area should be calculated independently of the pesticide used by adding up the estimated areas of all the targets sprayed during the day – see p. 49 for a method of estimating target area.

?

FAQ number 13 (see p. 82 for answers)

How can we find time to fill in a spray monitoring form when we are busy with control operations?

Why assess mortality?

- to see if the pesticide is working
- to see if the application is good
- to report confidently and accurately on the efficacy of the campaign

Mortality assessment techniques

Type	Target	When
Rough visual estimates	Swarms, bands and scattered locusts	Always after spraying
Counts of pre- and post-spray locust numbers (density assessments and target area measurement)	Bands and scattered locusts	Occasional spot checks especially when new products, dosages or techniques are being used, or if there are control problems
Cage assessments	Swarms, bands and and scattered locusts	As above, especially when using slow acting products on fast moving targets

How to assess locust mortality

The efficacy of locust control should be assessed frequently 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 has two purposes: to assess whether a repeat spray is required, and to check that insecticide and control technique are effective – if there are problems with the spraying, changes will have to be made before more (possibly ineffective) treatment is carried out. The assessment team needs to visit the target before spraying and some time afterwards to check it. This follow-up visit will usually be at the end of the spraying day or the following day, but timing of the efficacy assessment depends on the speed of action of the pesticide used and may be several days later.

Even with excellent application, it is unrealistic to expect 100 percent locust mortality. There are many reasons for this including locusts being sheltered from the spray by vegetation or each other, locusts not feeding just before a moult and gaps in spray deposition due to localized air movements. In practice the objective should be at least 95 percent mortality.

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. However, if it is clear that a substantial number of locusts are not being killed by control operations, it may be necessary to estimate the percentage kill so that the failure can be reported properly and appropriate action taken.

Even a rough estimate is often technically difficult because locusts can move out of the target area after spraying. This is especially true with slower-acting products which allow the locusts to move much further before they die. There are also practical difficulties because the Locust Field Officers will probably be busy with other control operations in other areas on the following days. More accurate mortality measurements can only really be made on settled targets (bands or swarms) – assessing mortality in flying swarms is very difficult and in practice is limited to checking whether or not any significant swarm still exists a day or more after treatment.

There are two main approaches to assessing mortality of settled targets: field assessments and cage assessments. Field assessments are a true efficacy test, but are not always easy to carry out, e.g. if locusts move before dying. Cages are an artificial environment but can still give an indication of field mortality if used correctly. They also have the advantage that the monitoring team can move on to other sites, taking the cages with them, and still obtain a rough estimate of efficacy at a previous spray site.

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FAQ number 14 (see p. 82 for answers)

The locusts are still alive after spraying – what are the possible causes of control failure?

Figure 31. Counting locusts in ten imaginary quadrats in a hopper band.

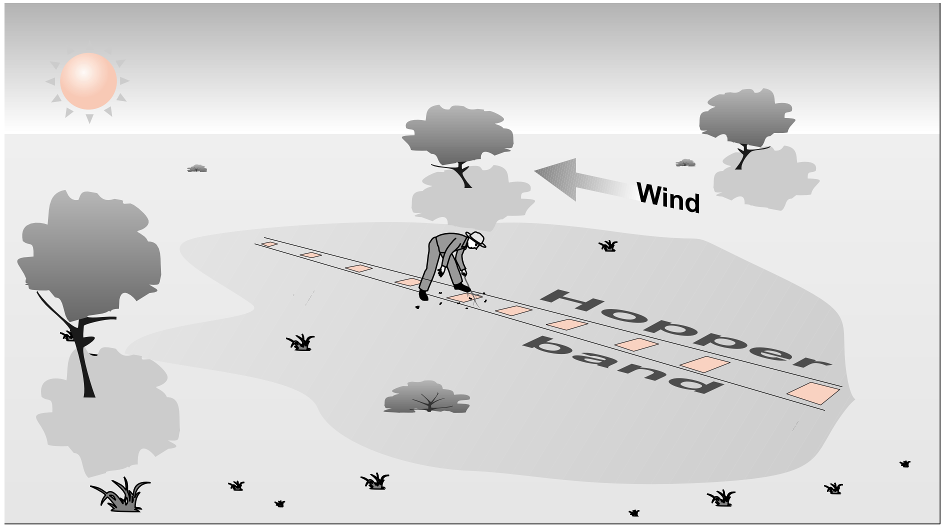


Figure 32. Counting locust hoppers in an imaginary 1 m² quadrat.

Field mortality assessments

Estimates are 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 the 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 locust density in it.

Measuring the approximate size of the target

A similar method can be used as for measuring the size of bands or swarms, i.e. two transects are driven or walked at right angles to each other along two sides of the target to measure its length and its width so that the approximate area of the target can be calculated (see p. 42-43 in the Survey guideline).

Measuring the average density of locusts in the target

Hopper density can be measured by walking a transect (see Fig. 31) and making at least ten quadrat counts of the number of living locusts in 1 m^2 within the target and the average number calculated. This technique may work for adults in a swarm but only if they are immobile such as when temperature are low. After spraying, 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 perching normally on vegetation, it is alive. If it is lying on its side or back on the ground, even if it is 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 your feet apart to form a base almost 1 m wide (see Fig. 32). A stick is useful for moving vegetation and flushing locusts from underneath it. If locust numbers are large, an estimated 1/4 m^2 can be used instead and the figure multiplied by four to give number per m^2. If the locusts are very mobile the counting must begin before reaching the imaginary quadrat because locusts will jump (or fly if adults) out of the quadrat before the person arrives. For active adult locusts, the transect count described in the Survey guideline (p. 15) may be more appropriate. All these assessments are estimates which vary greatly 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, the post-spray count 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 biopesticides. The post-spray counts will have to be done up to 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 stages.

Summary of the problems with field mortality assessments:

- if the insecticide affects locust behaviour, e.g. makes bands disperse or seek shade
- quadrat counts will flush locusts out of the counting area and therefore result in an underestimate of density
- dead locusts cannot be counted accurately 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

Tips:

- ***each person uses a slightly different method for counting locusts, therefore, the same person or people should make the pre- and post-spray counts to ensure that the results are consistent***
- ***methods may have to be developed to suit particular cases. For example, pyrethroids disorientate the insects and also make them seek shade. It may be necessary to find a technique to estimate roughly the numbers of locusts climbing up trees and bushes after spraying***

Calculations for field mortality assessments

Step 1. Calculate the average locust density by adding together the ten quadrat counts and dividing by ten

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:

$$\textbf{Approx. mortality (\%)} = 100 - \left(\frac{\textbf{post-spray numbers alive X 100\%}}{\textbf{pre-spray numbers alive}}\right) \qquad \textit{Formula 4}$$

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. It should be stressed that there is not usually time during control operations to carry out such detailed mortality assessments. If this method is used, the formula below can be used to calculate mortality:

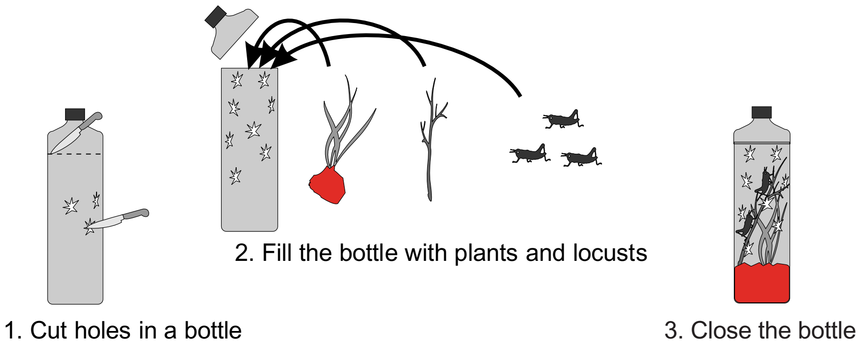
$$\textbf{Approx. mortality (\%)} = \left(\frac{\textbf{dead X 100\%}}{\textbf{alive + dead}}\right) \qquad \textit{Formula 5}$$

!

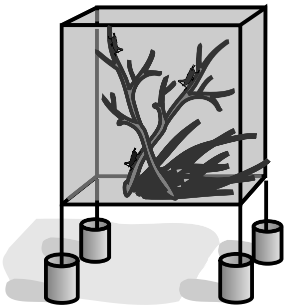
Care should be taken on re-entering sprayed areas – always wear protective clothing including gloves, do not eat or drink during counting and always wash body and protective clothing afterwards.

Figure 33. Two methods of making cages: (A) from plastic bottles and (B) from wood and gauze.

A. Plastic bottle cages



B. Wood and gauze cages



Tip: there are various 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 are bulky to transport***

Cage mortality assessments

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 (see Fig. 33A). Gauze netting held on with an elastic band can be used instead of the plastic top to prevent build-up of moisture which might kill the locusts. Cages can also be made using a wooden or wire frame covered in gauze, from cardboard boxes (which are convenient since they fold up for transportation), plastic buckets with mosquito netting across the tops, and many other materials (see Fig. 33B). Care should be taken to keep cages 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 as in Fig. 33B. If the sprayed locusts were on vegetation, some of that sprayed vegetation should also be put into the cage – remember that a locust often picks up an extra dose in the field by rubbing against and feeding on the sprayed vegetation. If locusts were sprayed on open ground, 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 on to 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 eight cages should be kept. Six of these should contain sprayed locusts/vegetation and two unsprayed locusts/vegetation as controls. Each cage should contain several insects (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 locusts should be counted at intervals after spraying. If there is more than about 10 percent mortality in the control cages, the results are unreliable because they show that catching and/or caging has caused some additional mortality.

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 Survey guideline (p. 41).

Figure 34. Storekeeper checking dates on pesticide drums.

Tips:

- *the pesticide store should be well-ventilated, far from buildings where people are living or working, far from livestock, and kept locked when nobody is inside*
- *washing and firefighting equipment should be kept in the store*
- *the store should only be used for pesticides and related equipment, and definitely no foodstuffs*
- *the storekeeper should keep good records and operate a first in, first out principle (use the oldest stocks first)*
- *pesticide drums should be placed on wooden pallets to prevent corrosion*
- *drums should not be stacked more than two layers high otherwise there is a risk that they will fall off and injure someone*
- *the storekeeper should open the door for a few minutes before entering to help ensure that any remaining pesticide vapours can escape, and should regularly clean out any accumulated dust*

CLEANING, STORING AND DISPOSING OF SPRAY MATERIALS

It is very important to make sure that spray equipment and insecticides are ready for the next locust control campaign, and that empty containers are disposed of properly.

Sprayers

It is much easier to clean and service a sprayer immediately after control is finished than to do it when the sprayer is required again several weeks or months later – the insecticide will have hardened inside and outside the sprayer and will be very difficult to remove.

Engineers, technicians and drivers should wear protective clothing when handling used sprayers. After draining any unused insecticide back into the original containers, sprayers should be cleaned with diesel fuel or kerosene, any repairs and maintenance carried out and the sprayer stored in the shade away from blowing dust or sand. The outside of the sprayer can be cleaned with a cloth soaked in diesel fuel or kerosene and the inside cleaned by putting some diesel fuel or kerosene into the tank and spraying it off over the target area or waste ground. Manufacturers' handbooks have information on routine maintenance and repair procedures.

Insecticide storage

Insecticides should be stored in their original containers in cool shade to prevent the chemicals being broken down faster by high temperatures. The insecticide store should be organized on a first in, first out basis, in other words the oldest insecticides of a particular type should be used first. There should be someone responsible for keeping records of the insecticides in stock – the storekeeper – and he/she should keep the store locked.

Disposal of pesticide containers

Many accidents have been caused by empty pesticide containers being used to store food and water. Empty pesticide drums should be cleaned inside and out with diesel or kerosene (water will not clean out the oily ULV formulations) and the small volume of washings should be disposed of by adding them to the pesticide in sprayer tanks during control operations.

These empty containers will still contain significant quantities of pesticide so should be stored securely to ensure they are not taken into use by local communities. If they are to be recycled, they should be transported back to the pesticide manufacturer. If they are for disposal, they should be punctured, crushed and transported back to the national authority for appropriate disposal.

More detail on pesticide storage and disposal can be found in the FAO Manual entitled *Pesticide storage and stock control*.

FREQUENTLY ASKED QUESTIONS (FAQS)

1. What is the spray target – the locusts or the vegetation?

Answer: For most spraying, both are the target since the locust gets some of its dose from direct contact, and some from indirect contact and stomach action – rubbing against and feeding on the sprayed vegetation.

2. When should helicopters be used instead of fixed-wing aircraft?

Answer. Helicopters have both advantages and disadvantages. They can fly more slowly, are more manoeuvrable so they can turn back to check on suspected targets and can land without an airstrip which makes survey and mortality assessments much easier. They can also spray more safely than fixed-wing aircraft in narrow valleys. However, they are much more expensive to operate and usually slower for spraying so they should only be used when the campaign organizer judges that the extra expense is worthwhile.

3. What can the spray team do if there are no sprayers with rotary atomizers available or working, i.e. only sprayers with hydraulic or air-shear nozzles?

Answer: Spraying ULV products through non-rotary atomizers can be inefficient and ineffective. However, sometimes action must be taken with whatever equipment is available, so steps must be taken to do the best job possible. For boom and nozzle equipment fitted to aircraft, small nozzles must be used (and some nozzles may have to be blocked off) in order to achieve a low enough flow rate and reasonably small droplets. The nozzles must be inclined forward at about 45 degrees as in Fig. 25 of Appendix 1.10. For most air-shear nozzles, all that can be done is to ensure that the flow rate is low enough and that the maximum airblast is used to get the smallest droplets possible. For the exhaust nozzle sprayer, Fig. 30 and 31 in Appendix 1.10 show the nozzle configuration that must be used to get the best possible droplet spectrum. In some cases a narrower track spacing must be used than could be used with a rotary ULV sprayer because the larger droplets are not being carried very far by the wind. The flow rate must either be decreased accordingly or the forward speed increased in order to maintain the volume application rate (VAR) and the recommended dose.

4. How many spray droplets must deposit on the vegetation or on the locust to be sure of a reliable kill?

Answer: Since the volume of a spray droplet varies so much with its size, it is not possible to say how many droplets of an unknown size are required. A locust will be killed by two droplets of 200 µm, 16 drops of 100 µm, and over 100 drops of 50 µm diameter. Since measuring the size of droplets on oil-sensitive paper cannot easily be done in the field, it is difficult to check whether the dose impacted on papers in the target area will be sufficient to kill locusts. The droplet collection characteristics are very different for papers and locusts so the number on the papers may not be representative. At best, they can give a guide as to whether there is a significant amount of spray depositing in the target area (say 5-50 droplets/cm^2) and whether there are significant deposit gaps where there

are no droplets. If ULV spraying is carried out with good equipment, properly calibrated to give the correct droplet size and dose, operated properly in good weather conditions, deposition should be satisfactory and a good mortality will result.

5. What criteria do the Pesticide Referee Group (PRG) use to judge insecticide trial reports?

Answer: The PRG produces a report that comments on any new developments in suitable pesticides for locust control and advantages and disadvantages. These developments are usually in the form of field and laboratory trials. The PRG tabulates efficacious dose rates and speed of action of each one, and, separately, their environmental risk (see Appendix 3.1). The criteria for judging the trials are that they should have been conducted to the highest scientific standards and that they comply with the FAO protocol for Desert Locust control trials.

6. Do different stages of locusts – early instars, later instars, adults – require a different dose of insecticide to kill them in the field?

Answer: Different stages certainly have different susceptibilities to insecticides – old fifth instar nymphs seem to be the most tolerant, possibly because it is difficult for the insecticide to penetrate their thick cuticles. However, it is not advisable to alter the dose depending on the stage of the locusts since this will complicate the control process because of the need to recalibrate for every different type of target encountered. This would also be difficult in practice due to their often being many different stages present in a target.

7. How can the track spacing and forward speed be measured reasonably accurately in the field?

Answer: Procedures for measuring track spacing and speed are described in Appendixes 2.2 and 2.3.

8. What can the spray team do if they must control locusts urgently but weather conditions are not suitable for ULV spraying?

Answer: It is not advisable to spray when conditions are not suitable. However, sometimes controlling the locusts must be done despite less than ideal conditions of wind and convection, e.g. if a swarm is about to take off or if a hopper band is entering crops. It is at these times that the Locust Field Officer must have a good understanding of the principles and processes involved in ULV spraying in order to produce an effective and efficient result. For example, if the wind is very weak, the officer may decide to spray anyway in an emergency. In this case, if he/she reduces the track spacing because the wind is not carrying the spray very far, he/she must also decrease the flow rate or increase the sprayer speed in order to keep the volume application rate the same and apply the recommended dose. Similarly if conditions are very hot and there is convection occurring, but it is very important to control the locusts immediately, the Locust Field Officer may decide to increase droplet size by reducing rotary atomizer speed and go ahead with spraying. In some instances these non-ideal applications may fail, or be very inefficient, but the risk of this may still be acceptable in cases of emergency – the decision rests with the Locust Field Officer. If the officer has oil-sensitive paper, spot checks can be carried out on the distribution of spray under different conditions.

9. What tactics can be used if hopper bands are under tall, dense vegetation such as a millet crop or on the downwind side of dense bushes?

Answer: For tall vegetation such as a millet crop, using a smaller droplet size will assist penetration. This does not seem correct at first since large droplets fall faster, but all the larger droplets will be filtered out in the upper canopy of the crop. Small droplets will drift slowly through the crop and will have a very low impaction efficiency (see Fig. 3 on p. 8). In other words, some of them will miss the upper vegetation and reach the lower parts of the plant and the locust. If hopper bands are on the downwind side of dense bushes, knapsack mistblowers can be used, but must not be sprayed directly upwind otherwise the operator will be contaminated – they must be sprayed crosswind. Alternatively, the control teams can wait for the locusts to move off the vegetation and start marching on more open ground.

10. If there are no aircraft sprayers available, how can locusts in tall trees be sprayed using ground-based sprayers?

Answer: Most ground sprayers, even motorized airblast sprayers, cannot reach swarms in tall trees and attempts at control can be very wasteful of pesticide and dangerous for operators standing underneath the spray cloud. However, a version is available with an extended mast that can be used in trees up to around 10 m height (see Fig. 23 in Appendix 1.10). This cannot easily be used on the move since the mast would break over rough ground, so should be used in short blasts at different locations upwind of the swarm. The concept of dosage does not really apply, and the process is likely to be wasteful, but may be effective.

11. How can small patches of locusts be sprayed using ULV equipment?

Answer: Spraying small targets with ULV spraying can be wasteful. The most appropriate type of sprayer should be used, i.e. handheld sprayers for very small targets. If the patches are still smaller than a swath width, then a double pass can be made at a short distance upwind of them. This requires that the sprayer operator and Locust Field Officer have a good feeling for where spray goes from a ULV sprayer.

12. How many droplets should be found on oil-sensitive paper in order to give good locust mortality?

Answer: FAQ number 4 deals with this question – it is very difficult to get anything other than an idea of whether spray is depositing at all from the oil-sensitive papers, since droplets of different pesticides spread different amounts when they land on the paper.

13. How can we find time to fill in a spray monitoring form when we are busy with control operations?

Answer: Locust control operations are hectic and monitoring is an extra task which requires time. However, it is worth assigning the task of spray monitoring to one particular member of staff so that it is one of his/her responsibilities. With a little practice, it does not take long to fill in the form – not all of it has to be completed for each target – and when the cost of the operations is considered, it can be seen that a little feedback can help to improve operations and save many thousands of dollars, as well as helping to ensure more efficient control.

14. The locusts are still alive after spraying – what are the possible causes of control failure?

Answer: It is tempting to blame the insecticide if control is poor, when in fact it is more likely to be caused by application problems. Failure can be caused by many factors including droplets too large or too small, wind too strong or too weak, strong convection, spray emission too high, underdosing, locusts sheltered by vegetation and locusts moving before the spray reaches them. Only when these factors have been eliminated should the pesticide be suspected and sent for testing for active ingredient content.