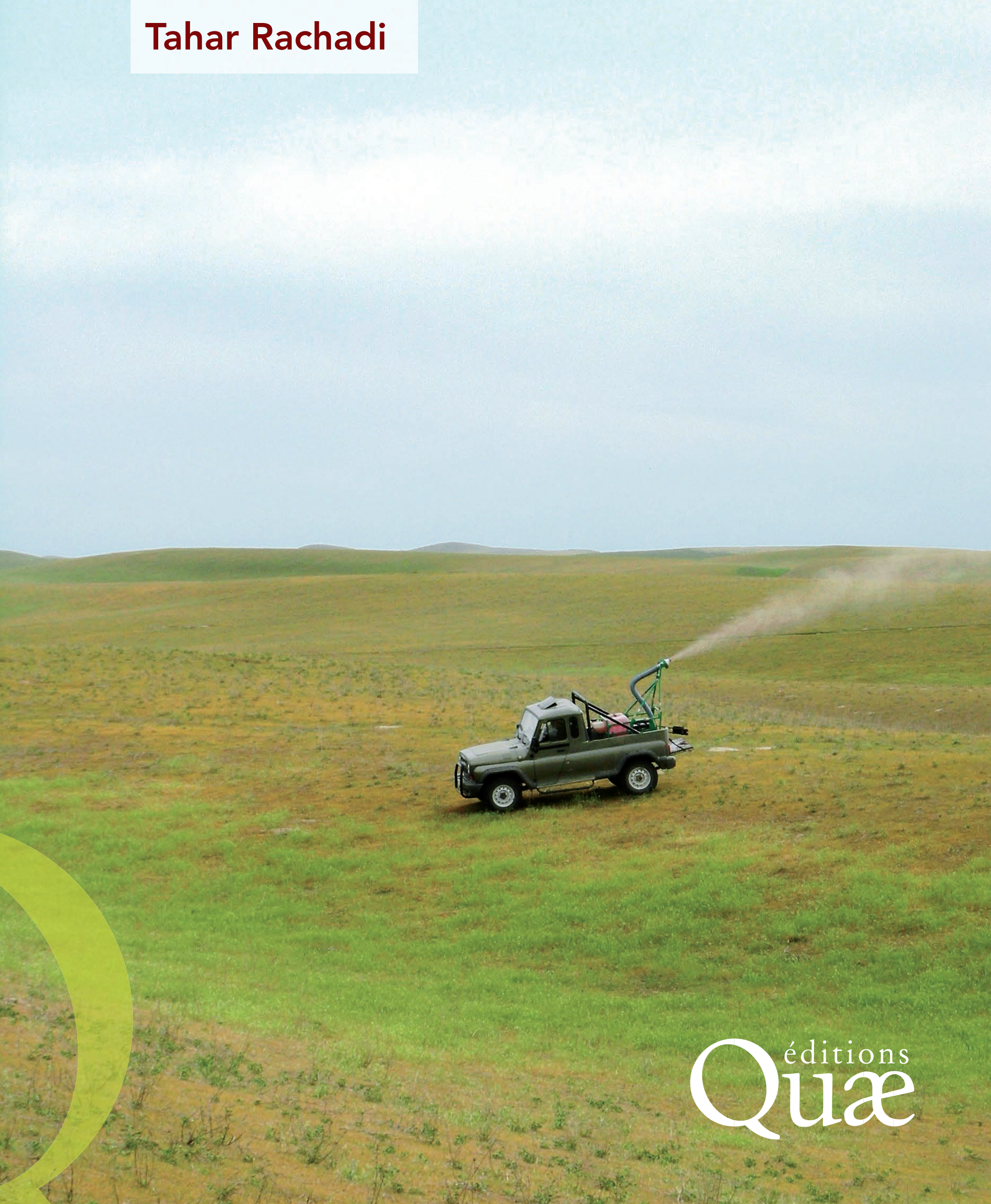
Guide pratique

Locust control handbook

Tahar Rachadi



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Tahar Rachadi

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Introduction

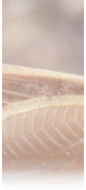
Availability of food in many developing countries is tenuous at best due to increasing population and climatic change which creates further challenges in what are often already marginal conditions for food production. Locust outbreaks and grasshopper outbreaks can dramatically reduce crop yields and instigate mass food shortage.

Apart from emergency situations in which the International Community plays an active role, locust and grasshopper control should be organised at local and national levels. Furthermore, management at the regional level is appropriate for countries which are likely to be affected by perennial outbreaks. At the time of the 1987-1989 Desert locust plague, large amounts of insecticides were sprayed on millions of hectares. The impact on the environment of such large scale applications is significant and therefore appropriate application techniques to minimise adverse effects and maximise control are critical.

Under these circumstances, applications of insecticides in locust control should be undertaken under optimal conditions of efficacy. That requires a multi-disciplinary approach, which combines entomology application techniques and socio-economics, together with the need to preserve the environment. The range of locust control operations, from individual farmer intervention to the use of aircraft, should also be considered. Of course it is imperative to prevent upsurges by controlling large scale locust outbreaks but that should not be done at any cost. It is essential to maximize the efficacy of the pesticides to reduce the quantity required for control.

From this point of view, enhancing and improving application techniques becomes an **economic and environmental necessity.**

Most of the documents and practical books devoted to locust control deal mainly with insecticides. There are a few which show how pesticides should be applied. It is obvious that good results cannot be expected if a product is spread with a watering can, because the active ingredient must be uniformly distributed on the whole area to be protected. It is however less apparent that a wide droplet spectrum spray can be equally wasteful. Very small droplets can drift far from the target (**exodrift**) and large drops will tend to fall directly on the soil (**endodrift**). Both have a negative effect on the environment and do not accurately target the locust



pest itself. Therefore it is essential to understand the application process in locust control as the most appropriate techniques are not always readily understood.

Both safety and effectiveness of pesticide use are to a large extent, determined by their method of application. In most cases of locust control, pesticides are applied using rotary atomisers to create a mist of small uniform sized droplets. The range of spraying equipment available is relatively sophisticated, thus requiring a high level of maintenance, training and skill in operation. By understanding the nature of locust and grasshopper outbreaks and the challenges involved in control, researchers can assist in improving current practices of pesticide application, increase control efficacy and improve safety for operators. Furthermore, an increase in control efficacy will result in a reduced pesticide use, lower costs and less environmental impact.

Since the discovery of synthetic insecticides, application techniques for locust control have developed rapidly. Pesticides have over the years become more potent and specific and therefore demand more precision in application. Application equipment has also dramatically improved thanks to the development of new materials and technologies. This resulted in significant improvement of ultra low volume (ULV) equipment and today it is widely used in aerial and ground spraying. During the 80's, more than 90 % of locust control applications were performed by implementing this technique, while water-based spraying, baits and dusting applications were negligible. Therefore the ULV technique and its equipment is an important tool in locust control and this book attempts to provide operators with a useful and practical manual, to guide them in the application process.

To be effective, any crop protection treatment should be applied at the right moment, in the right place, using the relevant product with the correct equipment, which should be well calibrated before application.

These precautions are crucial to avoid misapplications which lead to:
- a dramatic increase in application costs;
- a costly waste of chemicals, potentially hazardous for humans and the environment;
- increased risk to operators and non target organisms;
- excessive residues that contaminate the environment.

Poor calibration of equipment has other consequences. Failures in applications are often mistakenly attributed to failure of products. Sometimes when a treatment looks ineffective, operators overdose or apply multiple treatments.

This manual is intended to address application errors and the misuse of pesticides. The first section is concerned with the principles of ULV application addressing issues of droplet generation and meteorology. The second section introduces the various types of aerial and ground application equipment and the third section is concerned with operational procedures to maximise control efficacy, operator and environmental safety and minimise waste.

Spraying Principles

The application of crop protection products involves the atomisation of spray liquid into numerous droplets which are then dispersed over the target area. However, this definition is simplistic. To achieve accurate distribution on the target area requires the production of spray droplets of an appropriate size, neither too large which fall out onto the ground or too small which drift off target.

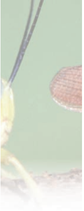
It is therefore important to understand the mechanics of spray droplet formation in order to understand how to select the most appropriate equipment and to teach operators to correctly calibrate and use only the minimal quantity of pesticide required to achieve control.

This chapter consists of five parts:

- The **target** and **active ingredient**. This section intends to define the locust or grasshopper target and its characteristics to find out the best way to reach this target.
- The **distribution and deposition of spray droplets**. This section discusses the droplet generation and methods of spray deposit assessment.
- **Spray volumes**. The description of spraying modes make it possible to prevent ambiguities which often induce wrong choice of anti-locust equipments.
- **Droplet transport**. The study of these concepts reveals the importance of the action of atmospheric agents upon spraying, particularly ULV technique. A good knowledge of atmospheric phenomena is essential to correctly perform ULV spraying.
- **Assessment of the spray quality**. The aim is to ensure that a spray is in accordance with the requirement and rectify any calibration error.

Target and active ingredient

To be efficient, a crop protection application should, at first, define the target in terms of time and space. A spray treatment will be most efficient if it is applied when the target pest is most susceptible, which requires knowledge of the target pest biology and behaviour. The space in which the target pest moves during the residual activity period of a given pesticide, should be understood. In fact, a given number of hoppers do not cover the same area as the equivalent number of flying locusts. The approach adopted with a locust should not be the same as for another locust or grasshopper.



Pesticide that does not reach its target is wasted and is an economic loss and an unnecessary hazard to the environment. Therefore, a good application should aim at achieving the maximum control with **minimum contamination of non target area.** This means that an application technique should attempt to reduce the quantity of pesticide while raising the quantity that actually reaches the target. This implies reducing leaching and uncontrolled drift. Whatever the pesticide, its mode of action should be known because all active ingredients are not the same. Contact acting, for example pyrethroids and organophosphates should not be applied in the same manner as IGRs (Insect Growth Regulators). To be efficient the contact acting pesticides must target the insect directly while the latter affects insects only after ingestion of contaminated vegetation. These data and the environmental characteristics should be considered for defining the spraying parameters which ensure the best way to attain the acridid target.

Except settled swarms or isolated hopper bands, the locust or grasshopper target generally consists of scattered population (scattered adults, scattered hopper bands) and the most frequent approach is to spray a defined area in which the insects wander, rather than treating directly the insects. In this case it is better to call it a **target area.**

Defining the target in terms of both time and space and the dose is the main factor for defining the objective of the treatment.

The locust target to be determined can be under three biological stages: egg, larvae (hoppers) or imago (adult). Being buried in the soil, the eggs are sheltered from sprayed insecticides. Hence it is hoppers and adults that constitute the locust target.

To define the locust target, several factors should be considered:

Threat

The threat posed by a locust infestation must be considered in both immediate and future time frame. Thereby the threat of a grasshopper population should be assessed according to the proximity and the susceptibility of susceptible crops; e.g. a field of millet is very susceptible at the emergence and grain formation stages. In contrast, a population of locust will be considered an appropriate target, as soon as it attains the gregarious stage, even when it is hundreds of kilometres away from any crop. This may seem disproportionate with regards to the evidence of damages.

Susceptibility

Hoppers, mainly young instars are reputed to be more susceptible than adults. The fact that they do not move very far makes them easier to control. Hoppers and adults may be more easily controlled in an open field rather than in a shrubby area or under a canopy.

Mobility

Locust adults may fly over tens or even hundreds of kilometres per day. During their life they may traverse thousands of kilometres. Swarms are good targets only when they settle, especially if they are less mobile when cold. Under hot conditions, the target is three-dimensional and fleeting. The same swarm can be seen in many places almost at the same time. In that case the biological target is capable of moving more rapidly than survey and control teams.

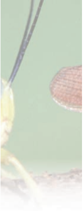
Hoppers are less mobile than adults as they only move by marching or leaping. Thus they form a more practical target. Hopper bands may march up to several kilometres per day. They constitute a relatively sedentary target for a few weeks which once located are easy to follow and treat.

Size

Within a uniform habitat where target outlines are similar, adults and nymphs of grasshoppers generally occupy the same space, whereas the area occupied by a swarm markedly varies during the day with temperature, wind, air stability, the nature and the structure of plant canopy and also with locust activity. Besides, it is frequent that a swarm infests an area twenty times larger than that covered by the hopper band from which it was originated. An inappropriate approach to treating a large swarm may result in partial efficacy and a fragmentation into isolated swarms, thereby creating many other targets covering a larger area and therefore much more difficult to control.

Hopper bands of locusts are often very dense, particularly at the young instar stages. Several thousand per square metre are often observed. The area covered by a hopper band may vary from less than a square metre to hundreds of hectares (fig. 1). They may break up into smaller bands but rarely disperse by individual means. Hopper bands are good target easy to define once located.

Figure 1. A hopper band of Desert locust (5th instar) crossing a road in Senegal (October 1988). Hopper bands of Desert locust may have a density of several hundreds of hoppers per square metre and may cover tens of hectares.



Droplet dispersal and deposit

Active ingredient and dose rate

A spray is a means to disperse, as evenly as possible, a given amount of active ingredient on a given area referred to as a dose rate and often expressed as grams of active ingredient per hectare (g a.i./ha).

Locust control operation should first ensure that the correct dose is applied. Control staff should particularly refrain from the tendency to spray over dose where locust density is high. In contrast they should not under dose in areas of low density.

Spray volume

The need to rapidly treat large areas particularly during Desert locust plagues, necessitates the implementation of considerable logistic resources. The need to apply products quickly had led to the development of Ultra Low Volume application technique to eliminate the need to mix products in water and treat vast areas quickly.

Research with the exhaust nozzle sprayer (ENS) demonstrated that efficacy was improved by reducing the volume applied as droplet size decreased and droplet number increased. **Consequently, utilizing a uniform spray with a small droplet size is much more efficacious than applying a higher volume of liquid.**

Classifications of sprays according to the volume applied per hectare are based on subjective criteria. The following classification distinguishes five types (tab. I): **high volume** (HV), **medium volume** (MV), **low volume** (LV), **very low volume** (VLV) and **ultra low volume** (ULV).

The ULV technique uses an application volume as small as possible while still conserving an optimal efficacy. Generally in crop protection the volume of spray applied depends on the type of target and the characteristics of the habitats such as plant coverage (tab. I). Sometimes, the type and active ingredient content of the formulation determine the volume of application in spite of target zone requirements. It is the responsibility of locust control officials, at national and regional levels, to assess the situation and provide their field staff with the most relevant formulation in order to meet the target requirement.

Type of spray	Quality of spray	Volume (l/ha)	Typical droplet size (µm)
High volume	Coarse	600 - 1,000	> 500
Medium volume	Coarse	100 - 600	300 - 500
Low volume	Medium	25 - 100	200 - 300
Very low volume	Fine	5 - 25	50 - 150
Ultra low volume	Very fine	< 5	40 - 60

Table I. Classification of sprays according to the volume of application per hectare.

Generally with aerial treatment, the volume of application seldom exceeds 1 litre per hectare as most operations take place in the areas with a low plant cover. However it is judicious to fix some limits so as to avoid excess. For practical purposes the lower spray volumes applied by air are 0.5 l/ha. However to apply such low volumes requires relatively uniform spray droplet sizes with µm around 50-60 µm. Use of uniform sized droplets is referred to as Controlled Droplet Application (CDA) after Mathews (1985).

ULV applications with water-based formulations are not suitable because locust and grasshopper control most often take place under hot and dry conditions and droplets under 200 microns are susceptible to quick evaporation.

Spraying for locust control can be defined as ULV: **a technique for producing even sized and small droplets using oil formulations with application volumes less than five litres per hectare.**

ULV formulations almost always are oil-based and applied without mixing (ready to use). When it is required to decrease dose rate or to rise the volume of application, it is possible to mix the original formulation with an oil. This oil should, of course be compatible so, tests should be made before final mixing. In this regard, the manufacturer of the pesticide should be consulted for recommended diluent.

1. Calibration

A formulation contains 450 g a.i./l. How much diesel must be added so that it is possible to treat a Desert locust infestation with 200 g a.i./ha or a grasshopper infestation with 150 g a.i./ha. In both cases the volume of application is 1 l/ha.

Note: to facilitate the calculations, cm³ or millilitres (ml) are adopted as units.

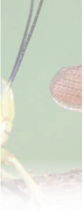
First, the ***quantity of formulation containing the dose*** *should be determined. For this purpose use the formula:*

Q = (D x 1,000) / C
where: ***Q*** *= the quantity expressed in* ***ml***
D *= the dose expressed in grams of a.i. per ha*
C *= active ingredient content of original formulation*

Case of the Desert locust: ***Q*** *= (200 x 1,000) / 450 =* ***444 ml***
Case of the grasshoppers: ***Q*** *= (150 x 1,000) / 450 =* ***333 ml***

Then, the quantity of oil diluent to add will be:
for Desert locust: 1,000 - 444 = ***556 ml***
for grasshoppers: 1,000 - 333 = ***667 ml***

So, 444 ml of original formulation will be mixed with 556 ml of diesel oil (444 + 556 = 1,000 ml) for treating 1 ha of Desert locust and 333 ml of original formulation will be mixed with 667 ml of diesel oil (333 + 667 = 1,000 ml) for treating 1 ha of grasshoppers.



Droplet density and spray coverage

The spray coverage is the number of droplets per unit area reaching the target. It can be assessed and expressed by **the number of droplets per cm² and is usually measured on the vegetation or oil sensitive paper targets placed in the vegetation on which the locusts move and feed**.

It should be noted that the density of droplets that contact the foliage in the target zone is high when the size is small and the efficacy is better when droplet number is high. So it is more efficacious to spray with numerous small droplets rather than a few large drops.

Type of vegetation	**Spraying equipment**			
	Aerial ULV	Vehicle-mounted	Battery-operated	Knapsack mist blower VLV
Grassy sparse	0.5	0.5	1	5
Grassy moderately dense	1	1	2.2	5.0 - 10.0
Grassy, dense discontinuous	1.5 - 2.0	2	3	10.0 - 20.0
Grassy, dense continuous	2.0 - 3.0	3.0 - 5.0		> 20.0

Table II. Volume of application (in l/ha) for spraying ULV and VLV, in relation to the vegetation and the type of equipment used.

Usually for ULV spraying, twenty droplets per cm² are sufficient with a contact acting insecticide, while in barrier treatment with persistent insecticides, the coverage decreases with downwind swath. Formerly, barrier treatments operated with dieldrin, had a good efficacy with 1 to 5 droplets per cm² (Castel, 1982).

Except in barrier treatment, in most cases of acridid control, 20 droplets per cm² are sufficient to ensure an acceptable efficacy.

Droplet size

When a droplet is falling, it forms a sphere. The diameter of the droplet indicates its size.

In the previous paragraph, it has been stressed that with equal doses the efficacy of a treatment is better when droplets are small rather than when they are larger. This is evident because small droplets have a better penetration into the foliage and thus the coverage is better. Similarly smaller drops are more effective at intercepting flying insects.

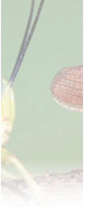
VMD	% of deposit	Type of use	Remarks
500	> 95	Application of herbicides, no drift accepted. HV or MV applications.	With aerial application the aircraft must fly very low.
200-500	80-95	Public health applications. LV applications on crops, including herbicides.	Suitable for water-based formulations, even for aerial spray.
125-250	50-80	VLV application of contact action insecticides and positioning on all crops.	Good coverage with VLV. Water-based formulations under cool and humid conditions
60-120	30-20	ULV application of contact action insecticides and positioning in most cases of crop protection. **Most used method in Acridid control**.	Good deposit inside canopy. Specific ULV formulations
30-60	15-30	Contact applications against flying or settled insects (mosquitoes, Tse Tse fly...). ULV method.	Strong drift. Low deposit. Application under atmospheric inversion
15-30	< 15	Aerosol for contact treatment against flying insects. ULV method.	Very strong drift. Almost no deposit.

Table III. Selecting droplet size according to the type of use (after Lerch, 1984).

For a given volume, small droplets cover a wider area, since the number of droplets available from a given volume is inversely related to the diameter. Thus, dividing by two the diameter of a droplet results in multiplying by eight their number and by two the area covered (fig. 2).

It should be noted that, according to their size, the behaviour of droplets is influenced by the gravity and air movement. Thus:

- Droplets of more than 300 microns fall downward, almost vertically under the force of gravity. In almost all cases these droplets will end up on the soil, because even if they are intercepted by the vegetation they are not retained (fig. 3). Large droplets contain the greater proportion of the sprayed liquid (i.e. of applied a.i.).



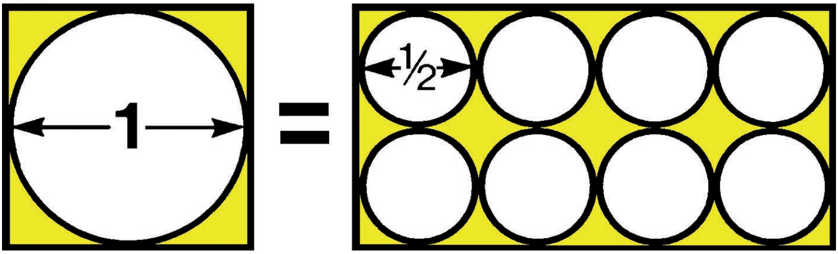


Figure 2. Relationship between droplet diameter and number (after Hoechst). For the same volume, dividing the diameter by two results in multiplying the area covered by two.

- Droplets between 100 and 300 microns also fall by gravity but they are subject to lateral drift by wind before being intercepted by vegetation or soil. They reach the target by sedimentation and by interception. They are moderately retained by vegetation.
- Droplets within 30 and 100 microns may be carried away, far from the emission point, by lateral wind movements while sedimenting simultaneously and progressively. They reach the target mainly by interception on foliage. They have a good penetration of the plant cover and they are retained on the foliage and on insect teguments (fig. 4).

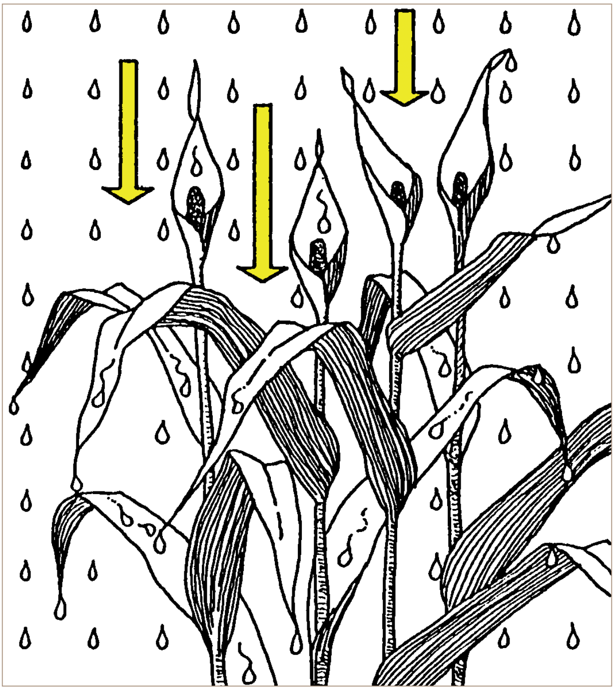


Figure 3. Large drops are poorly retained by the vegetation cover and generally end up on the soil (after Hoechst).

Figure 4. Small droplets reach the target by interception and have a good penetration of the vegetation cover (after Hoechst).

- Droplets smaller than 30 microns are very small and their trajectory largely affected by prevailing wind movements rather than gravity. They remain airborne, being carried some distance from the emission point. This type of spray is not usually used against locusts or grasshoppers as spray is often 'lost' from the target area due to convective air currents. Such small drops are used in public health against flying insects such as mosquitoes and Tse Tse flies (tab. IV) as the target is the air space in which the insects fly rather than the vegetation locust insects move and feed on.

Type of target	Coverage rate (droplet density per cm²)	Estimate % of deposit
Flying insects	Airborne droplets	15
Insects on the soil	20 - 30	15 - 40
Weed in post-emergence Fungus	30 - 40 50 - 70	40 - 80 50 - 80

Table IV. Droplet coverage and percentage of deposit according to the target type (after Lerch, 1984).

To achieve 20 droplets per cm², the amount of the spray liquid required is:

1 000 l/ha with 985 microns droplets,
200 l/ha with 576 microns droplets,
50 l/ha with 363 microns droplets,
20 l/ha with 267 microns droplets,
5 l/ha with 168 microns droplets,
4 l/ha with 156 microns droplets,
3 l/ha with 142 microns droplets,
2 l/ha with 124 microns droplets,
1 l/ha with 98 microns droplets,
0.1 l/ha with 46 microns droplets.

One litre of liquid applied evenly over a 1 hectare area achieves the following numbers of droplet/cm²:

387 droplets of 20 microns,
298 droplets of 40 microns,
88 droplets of 60 microns,
37 droplets of 80 microns,
19 droplets of 100 microns,
11 droplets of 160 microns,
2 droplets of 200 microns.

In ULV locust control, the size of useful droplets is within 50 and 100 microns. To reduce evaporation of droplets, ULV formulations should be of low volatility.

Droplet spectrum

Spectrum

Spray atomisers generally produce a range of droplet sizes, referred to as the droplet spectrum.

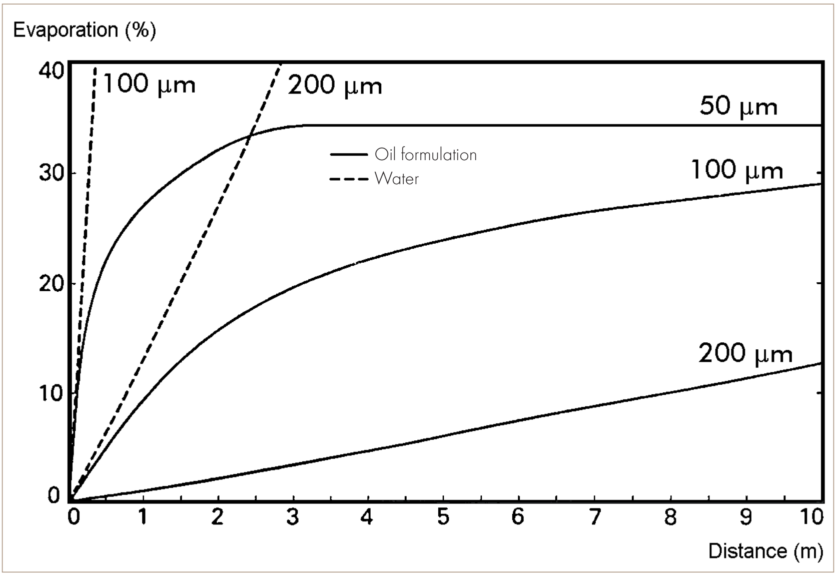


Figure 5. Evaporation rate of an ULV formulation, compared to that of water according droplet size and the distance between the emission point and the impact (after Ciba-Geigy, 1984). The assessment was realised in laboratory at 30 °C.

The droplet sizes produced by an atomiser can be expressed in various ways: the volume median diameter (VMD), the number median diameter (NMD).

Droplet diameter (microns)	Temperature (ºC)	Relative humidity (%)	Longevity (in seconds)
100	20	70	20
		40	9
	30	70	17 - 18
		40	8
	40	70	16.8
		40	7.8
50	20	70	5
		40	2
	20	40	1.9

Table V. Longevity of droplets of water according their diameter, air temperature and relative humidity (after von Eickstedt in Gröner 1985).

Volume median diameter (VMD)

The volume median diameter is the median diameter where 50 % of the spray volume is less than this sizing. Half of the volume of the spray is composed of droplets smaller than the VMD and half of it of drops larger than the VMD (fig. 7, p. 20).
Calculations can be made through image analysis of spray deposits under a microscope or using laser based particle size analysis to determine the VMD. To assess sprays quality under field conditions, the VMD may be estimated by using the following equation:

$$\mathbf{VMD = 0.45 \times D_{max}}$$

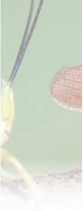
Where D_{max} is the diameter of the largest drop (the practice of determining D_{max} will be discussed in the paragraph entitled "the quality of sprays").

Number median diameter (NMD)

The number median diameter is the droplet size at which 50 % of the spray droplets by number are smaller.
If the droplets are ranged in order of magnitude and counted from the smallest upward, when 50 % of the number is reached then the diameter of the droplet at this median number is the NMD (fig. 7). Half of the total number of drops is below this value and half have diameters above it. On its own the NMD can be misleading in that it is influenced by large number of small drops which usually comprise only small proportion of the volume of spray liquid.
By dividing the VMD by the NMD we can derive a ratio that has often been used to determine the uniformity of a droplet spectrum. The lower the two values the more uniform the droplet sizes.

Uniformity of a spray

As a small number of large droplets contain more liquid than a large number of small droplets, the VMD is always greater than NMD.
Using the VMD/NMD ratio then the higher this value the greater the range of spray droplets.



For ULV application against locusts we require a very uniform spray droplet size with VMD/NMD ratios less than 2.
When SPAN is used to reflect the spray droplet size range then for locust control with ULV application we require values to be less than 1.

Spatial coverage

For wide area treatment, a good spray coverage is an important factor of efficacy. An important measure of spray coverage is the coefficient of variation Cv of spray deposits across the treated area. For short duration contact insecticides (less than 6 hours) the Cv should be small (less than 50 %) however with the longer acting pesticides – 24 to 48hrs – this is less important as the mobility to the locust or grasshopper will bring the insect into contact with the spray deposit. For residual sprays (for example insect growth regulators) with up to 3 weeks efficacy then the uniformity of spray deposit is not important as the active ingredient can be laid down in strips or barriers through which locust and hopper band move through.
For blanket treatment, a good spray coverage is an important factor of efficacy. The spatial coverage may be assessed by a ratio (fig. 8), which should be smaller as the a.i. has short residual activity. In other words the coverage should be even when the a.i. has a short residual activity.

Modes of spraying

Sprays may be categorised according to the mechanisms of droplet generation and the type of energy (nozzles).

Hydraulic energy nozzle

Liquid is forced under pressure through a small orifice so that the liquid spreads into a thin sheet and then ruptures into droplets of different sizes. Droplet size depends on the pressure, the type of nozzle and the size of the orifice. A low pressure together with large nozzle orifices produces larges drops. Whereas a high pressure with small nozzle orifice will produce smaller drops. With this type of spray however, the droplet spectrum is always very wide. The volume of the largest droplets may be as high as one million times the volume of the smallest.
There is a wide variety of nozzles with different forms and diameters of orifices available. There are several types of nozzles such as cone nozzle, fan nozzle and deflector nozzle. The flow rate and droplet size can be decreased but not sufficiently to make them small enough for ULV spraying. However, with cone nozzles (fig. 9) it is possible to perform VLV aerial spraying as the high air velocity from the aircraft will reduce droplet sizes further (fig. 10).

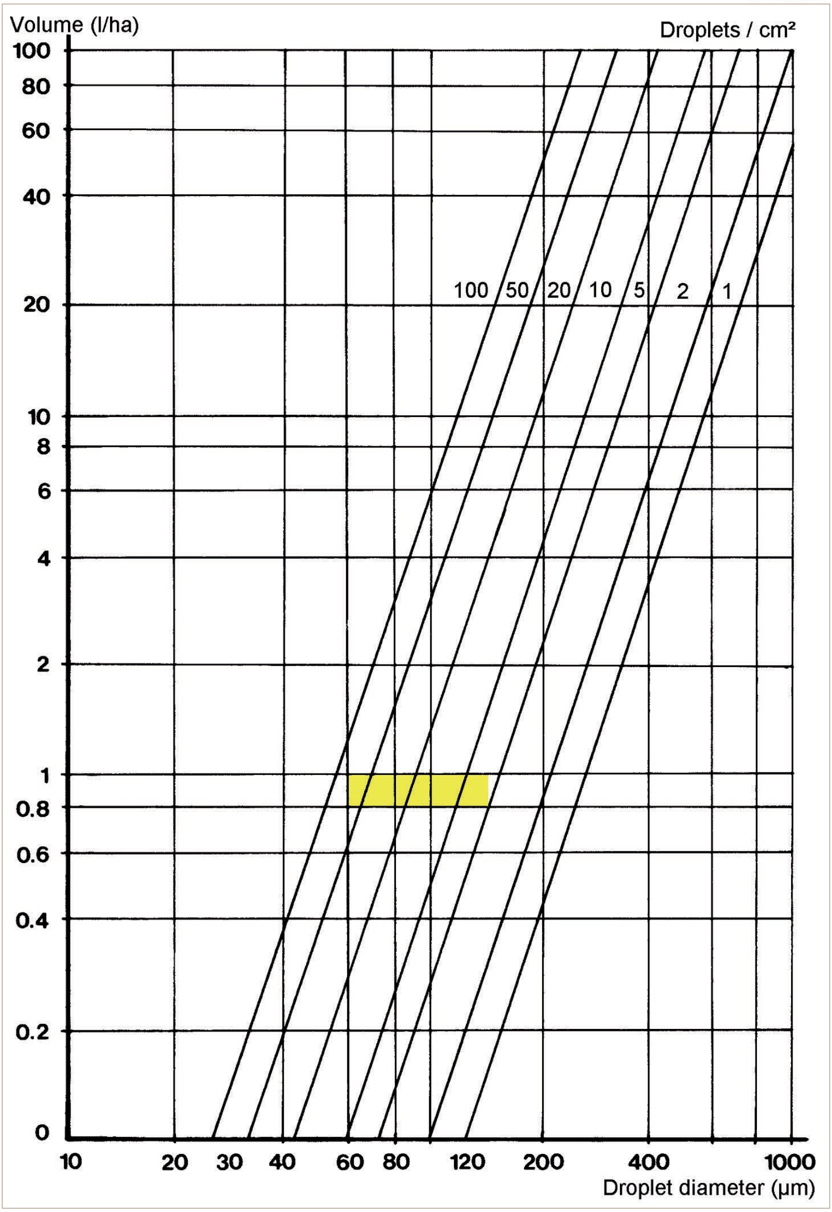


Figure 6. Relationship between volume of application per hectare, droplet size and coverage density (Castel, 1986).

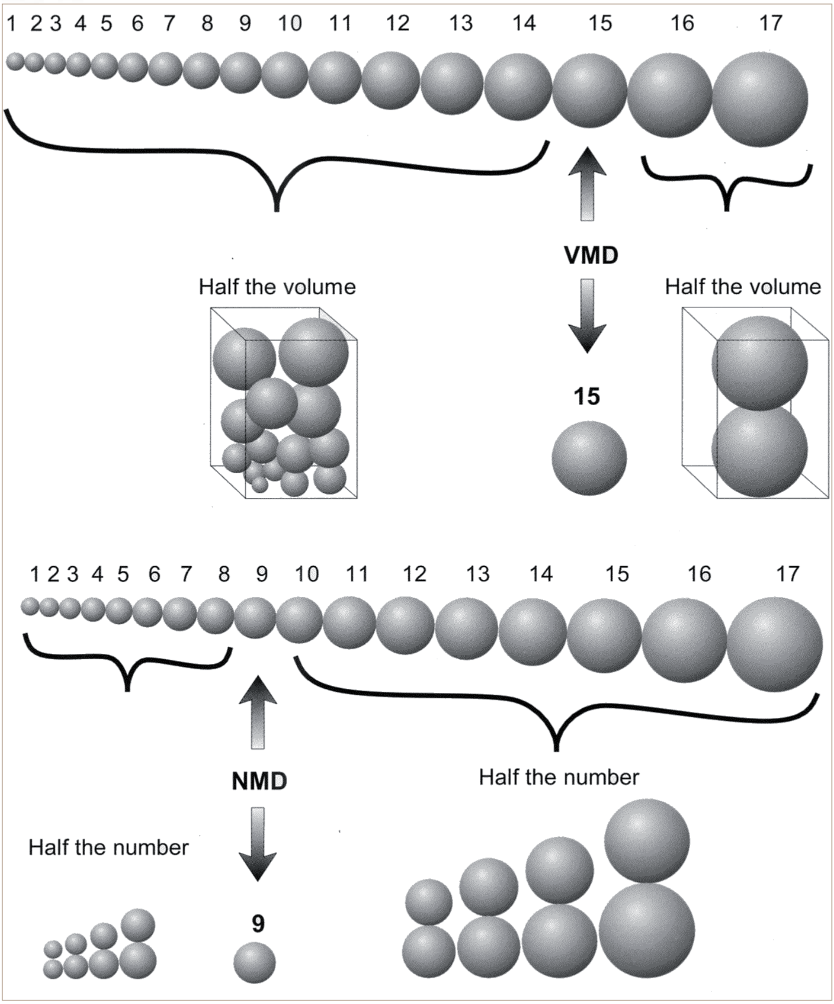


Figure 7. Diagrammatic representation of the volume median diameter (VMD) and the number median diameter (NMD) (after Dobson, 2001). Half of the volume of the spray is composed of droplets smaller than the VMD and half is larger than VMD. Half of the total volume composed of small droplets contains a significantly greater number of droplets than the half containing the largest droplets.

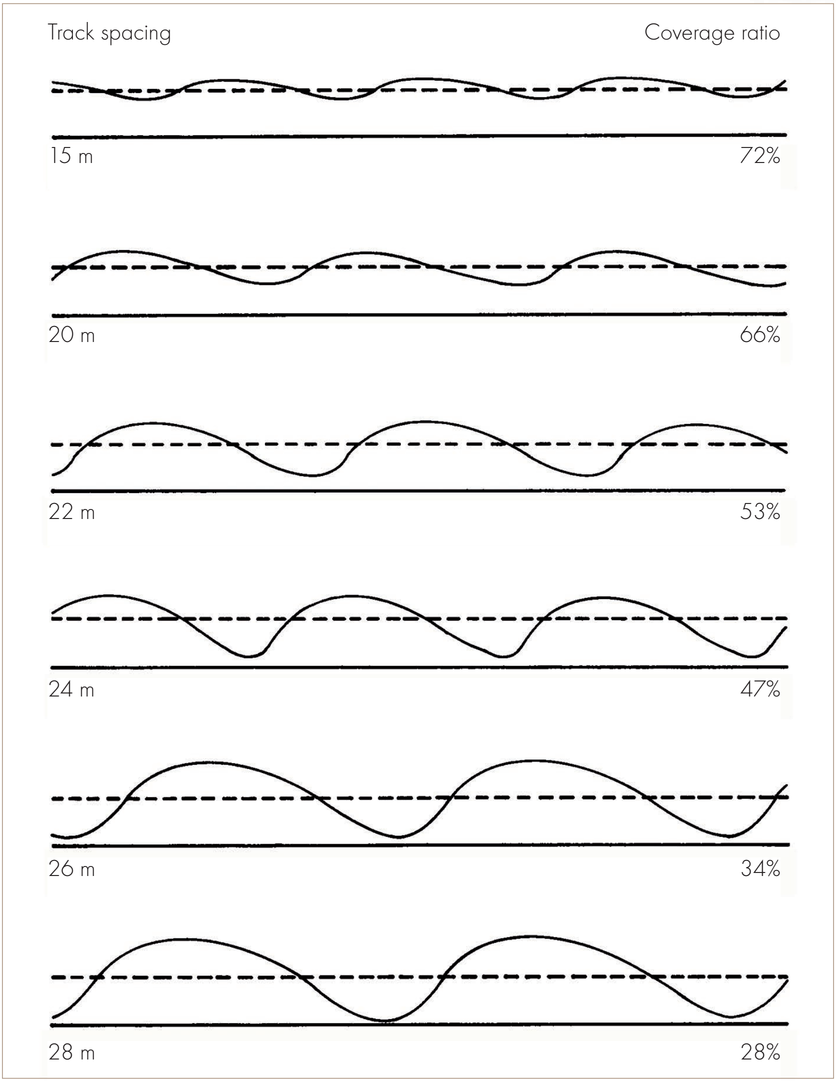
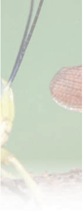
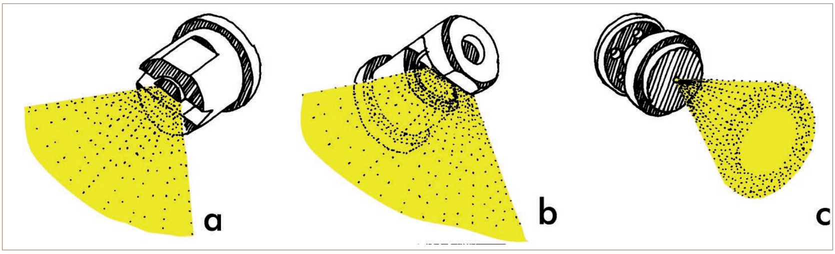


Figure 8. Spatial coverage ratio (after Ciba-Geigy, 1984). The shorter track spacing the greater coverage ratio.



Pressure (bars)	Droplet size (microns)	Time (second) for a trip of		
		0.25 m	0.50 m	1.00 m
1	50	0.094	0.290	0.700
	100	0.060	0.210	0.540
	200	0.034	0.100	0.380
2	50	0.084	0.220	0.510
	100	0.044	0.130	0.350
	200	0.022	0.061	0.200
4	50	0.057	0.150	0.420
	100	0.030	0.090	0.290
	200	0.015	0.041	0.140

Table VI. Flight time of droplets emitted by fan nozzles (after Dirske, 1986).



a: fan nozzle b: deflector nozzle c: cone nozzle

Figure 9. Three types of hydraulic energy nozzles for water based formulations (after Desmarquest).

Hydraulic energy nozzles are rarely used in locust control as they require large amounts of water (100 up to 1,000 l per ha) which is not readily available in many desert environments and severely restricts the areas that can be treated.

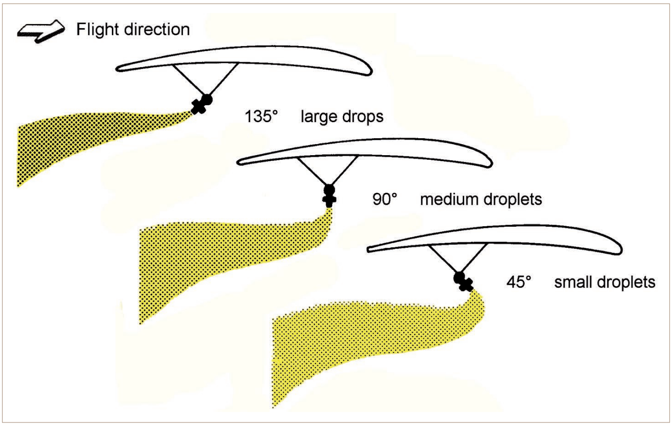


Figure 10. Orientation of hydraulic energy nozzles and its effect on the droplet size in aerial spraying (after Ciba-Geigy, 1984).

Gaseous energy nozzle

Droplets are formed by the action of a high velocity airstream on a thin stream of liquid at low pressure. This nozzle type is referred to as “twin fluid” because of the use of air and liquid. Liquid is fed at low pressure (0.2 bar). In the second the air at high velocity is produced by a turbine operated by an engine or by the power taken from the vehicle and pushed through a restrictor, producing a Venturi[1] effect in which airstream impacts the liquid (fig. 11). Impacting the liquid by a jet of air at high velocity through the restrictor disintegrates the liquid into droplets. Droplet size depends on the ratio liquid flow / air flow. Increasing in the air flow results in decreasing of droplet size and vice versa (tab. VII).

Flow rate of water (litre/min)	Droplet diameter (microns)
0.7	200
1.6	242
2.0	285

Table VII. Example of variation of droplet diameters in relation to the flow rate increase of mist blower knapsack sprayer (after Matthews, 1985).

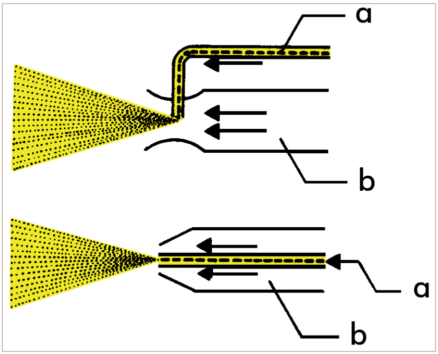


Figure 11. Two shapes of restrictors of pneumatic sprayers (after Musillami, 1982).

a: liquid circuit
b: restrictor for high velocity air

Figure 12. Centrifugal device mounted in the air pipe of a mist blower knapsack sprayer (Micron Sprayers).

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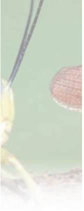
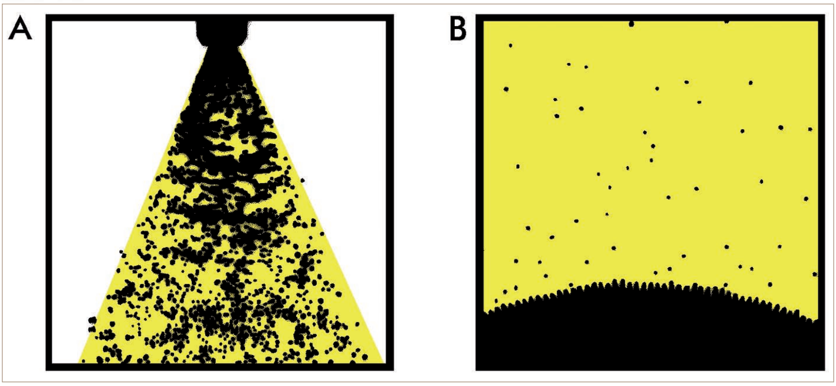
[1] It is the narrowing of the pipe. It increases the flow of the liquid. The process bears the name of its designer: the Italian physicist Giovanni Battista Venturi (1746-1822).





A: hydraulic energy nozzle B: rotary spinning disk

Figure 13. Comparison of droplets produced by a hydraulic energy nozzle and a rotary spinning disk (after Micron Sprayers).

Gaseous energy nozzles require high energy, hence high large power requirement.

One example of a simpler system was the development of the exhaust nozzle sprayer (ENS). The ENS is a typical gaseous energy nozzle which was very simple in design with no moving parts. The exhaust from a vehicle engine was used to generate gaseous air flow at the nozzle to shear the droplets. Droplet spectra was wide however when the ENS was used with the persistent organochlorine Dieldrin during the 1960-70s, which was not a problem. However for more modern and less persistent contact insecticides the ENS was not appropriate.

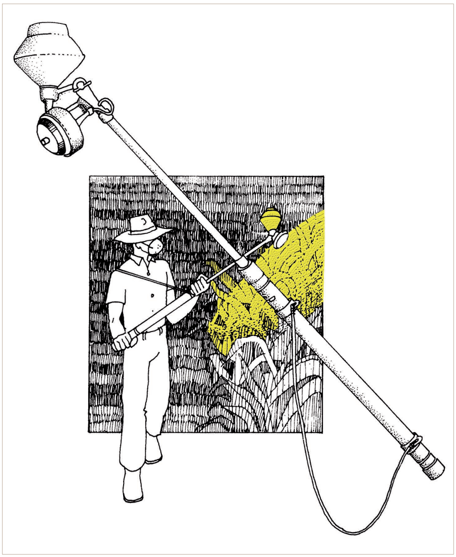


Figure 14. Tecnoma battery-operated sprayer Giro 1. This sprayer is fitted with a smooth disk.

Revolutions rounds/min	Flow rate (ml/min)	VMD (microns)	NMD (microns)	VMD/NMD
9,000	8.5	64	40	1.6
12,000	8.5	54	33	1.6
15,000	8.5	41	32	1.4
9,000	26.0	71	50	1.3
12,000	26.0	52	39	1.4
15,000	26.0	45	33	1.7
9,000	60.0	81	55	1.5
12,000	60.0	60	38	1.6
15,000	60.0	64	37	1.7

Table VIII. Effect of rotational speed and the flow rate on droplet spectrum, with hand-held ULV sprayer Mini ULVA (after Dirske, 1985).

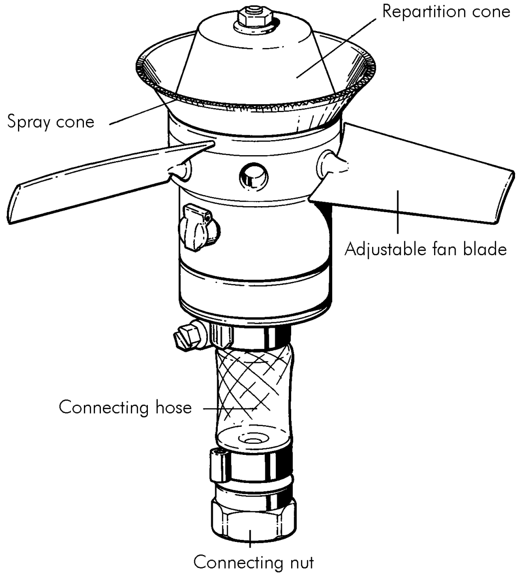


Figure 15. A cone-shaped and toothed centrifugal atomiser: Micron X-1 (Micron Sprayers).

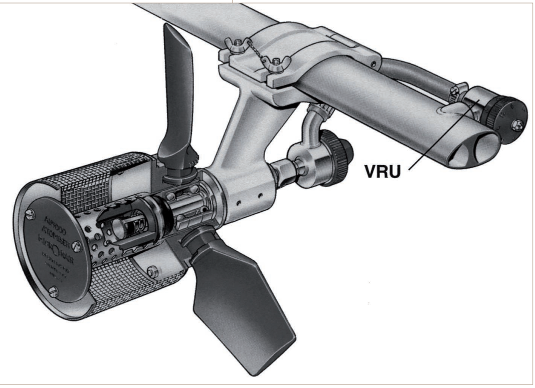
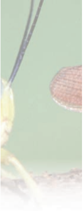


Figure 16. Micronair cage atomiser, type AU4000 (after Micronair). A typical rotating cage.



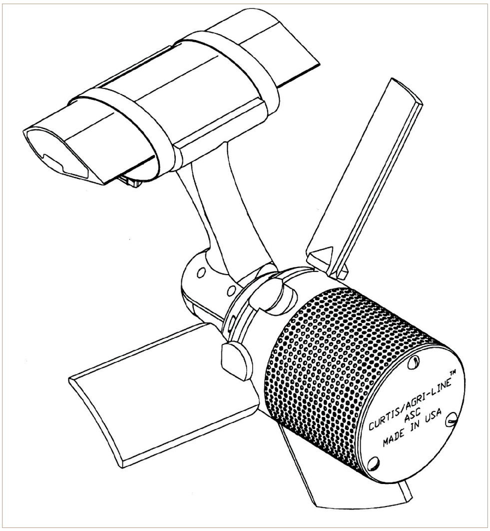


Figure 17. Curtis Dyna-Fog ASC-A10 cage.

Centrifugal energy nozzle (rotary atomisers)

In centrifugal energy nozzle, droplets are formed by a high speed rotation (typically 5,000-8,000 rpm) of a spray device. The liquid is fed at low pressure onto a rotating surface and the centrifugal force spreads it to the edge where the droplets are formed. The faster the rotation the greater the energy imparted and the smaller the droplets. This process allows droplet size to be adjusted independently of flow.

Droplet size also depends on flow rate and the viscosity of the sprayed liquid. In other words, for a given flow rate an increase of the rotational speed results in a decrease of droplet size and vice versa. For a given rotational speed, an increase of the flow rate results in an increase of droplet size (tab. VIII). Viscosity can also play a role in droplet size but more importantly can affect flow rate particularly through adjustable valves or orifice restrictors. Higher liquid temperatures have an important influence on viscosity.

Rotary nozzles can be operated by electric of hydraulic motors or fan impellors driven by an airflow or aircraft slipstream. Rotary nozzles generally produce a much more uniform droplet spectrum and have proved themselves ideal for ULV locust control at volume rates as low as 0.5 l/ha.

Spinning discs or rotating cages (fig. 16 and 17) are the most common.

Spinning disks

Most spinning discs have a tooth form to assist with more even liquid break up at the disc edge. Some are composed of a stack of many disks (Micron X9-DD). Rotating disks are normally operated by an electric motor: Micro Ulva+, Micron X-15 of Micron Sprayers, Giro 1 of Tecnoma (fig. 14), C8 of Berthoud.

Toothed disks produce droplets within a narrow spectrum: VMD varying from 40 to 80 microns and a VMD/NMD ratio from 1.2 to 1.7. Thus toothed disks provide

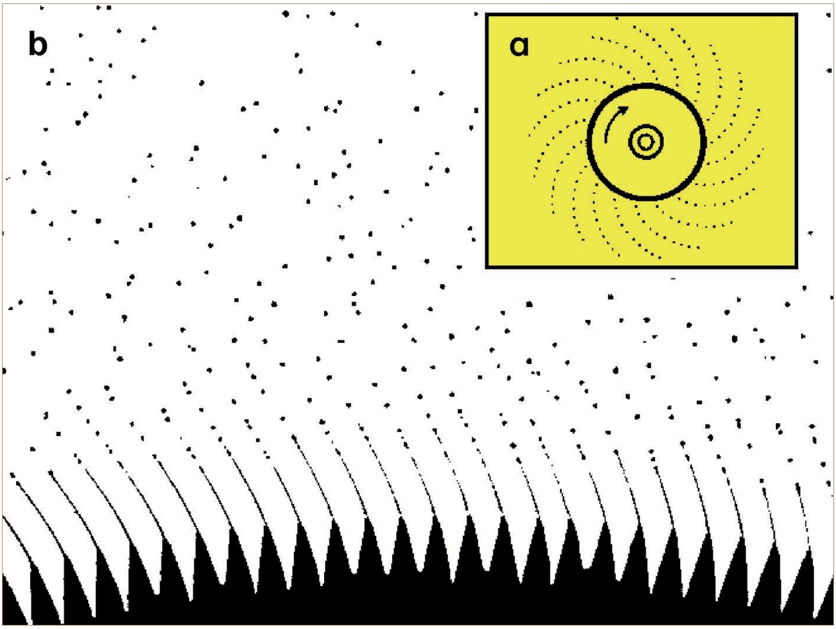
a very good means of droplet size control for locust operation. This concept is referred to as controlled droplet application (CDA) (Bals, 1978).

Rotary cages or cylinders

Rotary cages constructed from a mesh or perforated cylinders are often used on vehicle or aerial systems as fluid capacity of these devices is greater than discs. The cages consist of a cylindrical with a corrosion resistant and very fine metal wire gauze, rotating around a fixed hollow spindle (fig. 16). The cylinders are made from a high resistant plastic (fig. 17). The rotational speed of both cages and cylinders is high. Rotary nozzles may be operated either by the slipstream of flying aircraft by means of fan blades (Micronair AU5000 or ASC of Curtis Dyna-Fog), by electric power (Micronair AU6539 or Beecomist Airbi) or by a hydraulic system (Micronair AU7000).

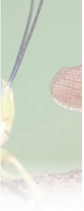
Liquid is fed through the hollow spindle then a spray deflector distributes the liquid over the rotating gauze or through the perforations. After an initial break up of the liquid, the atomisation is achieved when the liquid is accelerated at the rotating edge by centrifugal force.

Until the 1980's, rotational cages and cylinders were mainly used for aerial applications. Now, after recent locust plagues many ground materials were successfully equipped with those spraying heads. Adjustment of rotational speed is made by setting the angle of the fan blades (fig. 15, 16 and 17) or by an electronic speed controller.



a: running principle b: denticles and droplet formation on a spinning disk

Figure 18. Droplet production by a rotating and toothed disk (after Dobrowsky and Lloyd *in* Matthews, 1985).



Droplet transport

Droplet transport consists of the initial ejection of droplets during the atomisation process and thereafter the sedimentation and transport by wind and gravity.

Hydraulic energy nozzle

The energy that produces droplets also ejects droplets towards the target. Droplet path is very short because they are very soon stopped by the resistance of the air, even when they are emitted with a high speed in excess of 25 m/s. Only large drops are able to traverse several metres. So spraying directly onto surfaces requires that the emission point of droplets should be in the proximity to the target.

Spray process	Droplet transport by	Possible swath width	Type of equipment
Hydraulic energy nozzle	– Initial kinetic energy + air (air carrier) + gravity	– A few metres – A few tens of metres	– Knapsack sprayer – Vehicle carried – Aerial sprayer
Gaseous energy nozzle	– Air carrier then wind + gravity	– A few metres	– Knapsack mist blower
	– Air carrier + lateral wind – Upward jet	– A few tens of metres – 100 to 200 metres	– Knapsack mist blower – ENS
Centrifugal energy nozzle	– Air carrier + side jet – Lateral wind – Lateral wind	– 20 to 50 metres – 10 to 30 metres – 100 to 200 metres	– Knapsack sprayer – Hand-held ULV sprayer – Aerial application

Table IX. Atomisation method and droplet transport.

Air assisted sprayer

Most ULV sprayers rely on spray transport by wind and gravity. Air assisted sprayers utilise an initial air flow to project spray droplets higher so the height of release is increased and therefore the trajectory of fallen droplets will be carried further by the prevailing wind. This type of equipment is also useful for treating trees or in areas where the wind velocity is variable to help propel spray away from the vehicle. Droplets under 100 μm are more suitable for transport in an air stream.

Controlled drift spraying

Most ULV relies on the wind for droplet dispersal and a technique referred to as air drift spraying simply involves the release of spray droplets above the vegetation canopy and allows the prevailing wind and gravity to disperse the spray. This allows a distance of up to 50 m to be treated in a steady wind speed (52 m/s) from a vehicle sprayer or 10 m from a hand-held sprayer.

The use of ULV drift spraying relies on good and steady wind conditions, so the best time to spray is early morning or late afternoon.

Effects of gravity and sedimentation velocity

A droplet released in a still atmosphere will fall vertically and accelerate under the force of gravity but will soon reaches a steady velocity at which the gravitational force is counterbalanced by aerodynamic drag force. The fall will then continue at a constant terminal velocity which is referred to as **sedimentation velocity.** Droplets below 100 microns reach sedimentation velocity after 25 mm while those of 500 microns after around 70 cm. Density of liquid and droplet size, together with the air density and fluidity also have an influence on sedimentation velocity. From a practical standpoint, it is considered that the determining factor of the sedimentation velocity is the droplet size (tab. X).

Droplet size (microns)	Sedimentation velocity	Time for 10 m falling (seconds)
20	0.012	833
40	0.047	208
50	0.073	137
60	0.105	98
70	0.141	71
80	0.183	53
90	0.228	44
100	0.278	36
120	0.355	28
140	0.445	22
160	0.536	18
180	0.625	16
200	0.705	14
250	0.940	10
300	1.150	8

Table X. Sedimentation velocity of different sized droplets (after Quantick, 1985).

The important point here is that the longer the droplets are airborne after release the greater the distance they will be carried by the wind.

Wind speed and wind direction

The wind has a great effect upon the behaviour of droplets. When the wind is steady and consistent in direction, the effect is useful for transport, distribution and carrying droplets into the foliage.

Wind speed varies during the day so, if possible, it is always best to gauge wind strength and direction by measurement or by use of a simple flag.

The ideal wind is from 1 to 3.5 m/s (3.6 to 12.6 km/h). When wind speeds are less than 1 m/s, it is not recommended to spray.

The wind speed is measured by means of an anemometer. Wind anemometers can be sophisticated and have a digital display (fig. 19). There are also less accurate, but simpler, devices which give a good indication of wind speed such as a Dwyer^{TM} wind meter that relies on a ball being lifted within a calibrated column (fig. 20).

If no anemometer is available the Beaufort scale can be used (fig. 21).

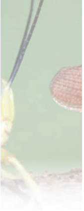


Figure 19. Digital display anemometer.
It displays the mean wind speed calculated over 30 consecutive seconds.

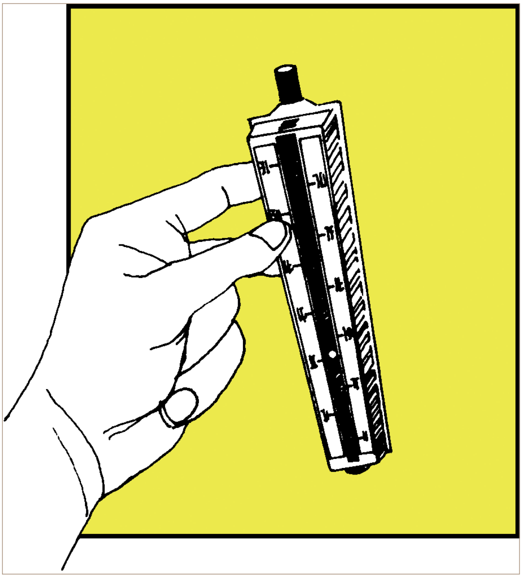


Figure 20. Anemometer Dwyer (after Matthews, 1985b).
Simple and practical, this hand-held anemometer is suitable for usual acridid control.

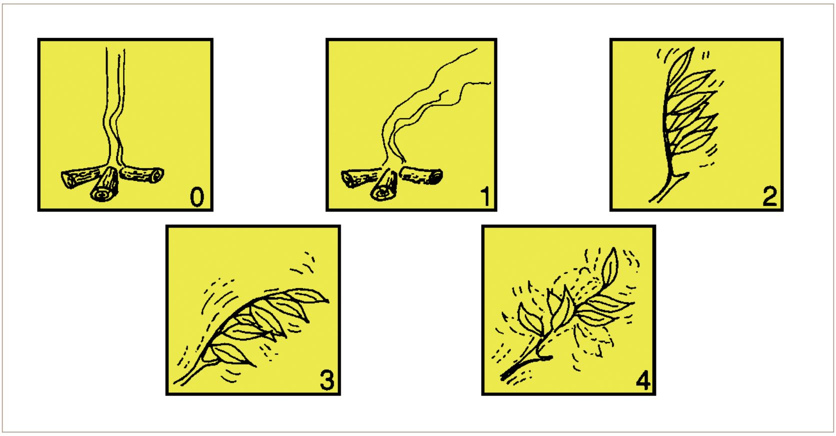


Figure 21. Evaluation of wind force with Beaufort scale.

The ideal wind direction should be the 90 degrees from the spraying path. But actually, these conditions seldom happen. However, treatment is still correct as long as the wind remains above 25 degrees to the spraying path (fig. 22).

Observing the plant movements in the treatment site will suffice to reveal the wind direction (branches of trees and bushes or herb stems). During aerial treat-

Wind force	Appellation	Features at ground level	Wind speed (m/s)	
			Mean	Extremes
0	Calm	Smoke rises vertically.	0.1	0.0 - 0.2
1	Slight puff of air	Wind direction showed only by smoke.	0.9	0.3 - 1.3
2	Slight breeze	Feeling wind on face. Leaves move. Wind vane turns towards wind origin.	2.4	1.6 - 3.2
3	Soft breeze	Leaves move, small stems. Light flag moves smoothly.	4.3	3.3. - 5.4
4	Moderate breeze	Rising of some dust and papers; small branches move.	6.7	5.5 - 7.9

Table XI. Limits of Beaufort scale use for estimating wind force in controlled drift spraying (after Castel, 1982a).

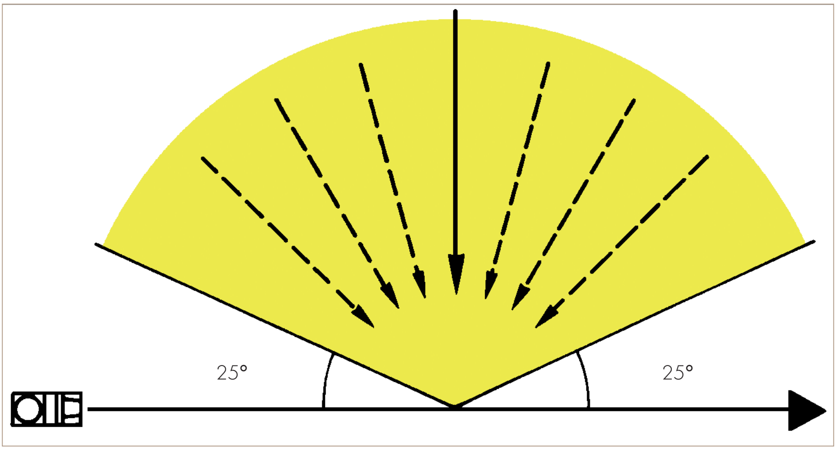
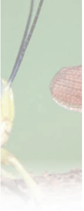


Figure 22. Angle of spraying path to the wind direction. Drift spraying remains acceptable so long as the angle of wind direction is above 25 degrees to the spraying path (after Micron Sprayers).

ments, a source of smoke will be suitable for it can be observed from a great distance by the pilot. For ground treatment, a bright coloured (tissue or plastic) strip fixed on top of a stake is sufficient to indicate the wind direction.

Spray emission height

Since droplets are likely to deposit at variable distances from their emission point, according to their size and the prevailing wind speed, it is possible to determine the actual swath width and fix the track spacing i.e. the distance between successive passes of the vehicle while spraying.



With no wind, droplets will fall vertically under the force of gravity. The falling time depends upon the size of each droplet (tab. X). Thus, the smaller they are, the longer they will stay airborne and drift with lateral wind. The smallest droplets will travel farther than the largest. The latter will impact near their emission point.
If the emission point is increased, droplets will drift further. The distance traversed by droplets before impacting results from both effects of gravity speed. This relation is summarised by the following formula:

$$D = H \times U / Vs$$

D: is the distance a droplet travels horizontally from the vertical of the emission point. It is **expressed in metres (m)**.
H: is the height of the emission point, **expressed in metres (m)**.
U: is the mean wind force during fall, **expressed in metres per second (m/s).**
Vs: is the sedimentation velocity of the droplet size range, expressed in **metres per second (m/s).**

Accordingly, droplets always deposit at the same distance "D" if the product "H x U" is constant. So, to keep the same swath width, the emission height should be lowered if the lateral wind speeds up and vice versa.

Although droplets larger and smaller, respectively than 30 and 120 microns may enhance general efficacy, it is usually admitted that useful droplets are comprised within 30 and 120 (Bals, 1978).

2. Example of downwind distance calculation

80 microns emitted droplets at 10 m high, under a wind of 2 m/s, will deposit at:

$$D = H \times U / Vs$$

$$D = (10 \times 2) / 0.183 = 109 \text{ m}$$

With a 4 m/s wind, keeping the same distance downwind requires a constant H x U value (20). Since U value is doubled (from 2 to 4 m/s), H value (10 m) should be divided by 2 (5 m).

Effect of atmospheric stability

It is well-known that in tropical climates temperatures normally decrease with increasing altitude. The rate decrease with height is referred to as the **temperature lapse rate**. Observations from sounding balloons reveal that the temperature lapse rate varies from place to place and from time to time. A typical lapse rate is around 1°C decrease in temperature for each increase of 100 m. However under certain conditions the temperature can actually increase with height, a phenomena which referred to as an **inversion.**
Inversion usually occurs in the low atmospheric layers, notably in the evening and early morning when the ground loses heat by radiation and is more cooler than the air above it. The surrounding air becomes cooler and tends to be heavier. Under inversion conditions temperatures increase with the height up to 10 to 15 m, then the temperature lapse rate prevails. Normally inversion is greatest

in the morning at dawn just before sunrise. The atmosphere is then stable with almost total absence of turbulence i.e. there is no vertical air movements.

There is an inversion when the air temperature at 2 m off the ground is 0.6° C higher than on the surface of the soil.

After sunrise, the mass of air which is close to the ground is warmed by radiation from the sun and will start to rise. It will continue to do so while it remains hotter and lighter than the surrounding air. This will result in a convective movement of air in an unstable atmosphere and thus turbulence conditions are enhanced (fig. 23). Under these conditions, successful deposits of the pesticide to the target site are reduced and erratic. On the other hand, inversions do not take place in still air and will not be problematic for aerial applications.

In tropical zones a day may be divided into several periods which are more or less suitable for drift spraying, owing to daily variation of atmospheric conditions. The magnitude of these suitable periods may vary with atmospheric conditions (temperature relative humidity and clouds). Practically (fig. 24), treatments utilizing CDS are possible in the morning between sunrise and around 10 a.m. and from 4 p.m. to sunset. At mid day, when there is no inversion droplet deposit is hindered by turbulence. **Therefore it is generally advisable to avoid drift spraying from 10 a.m. to 4 p.m.**

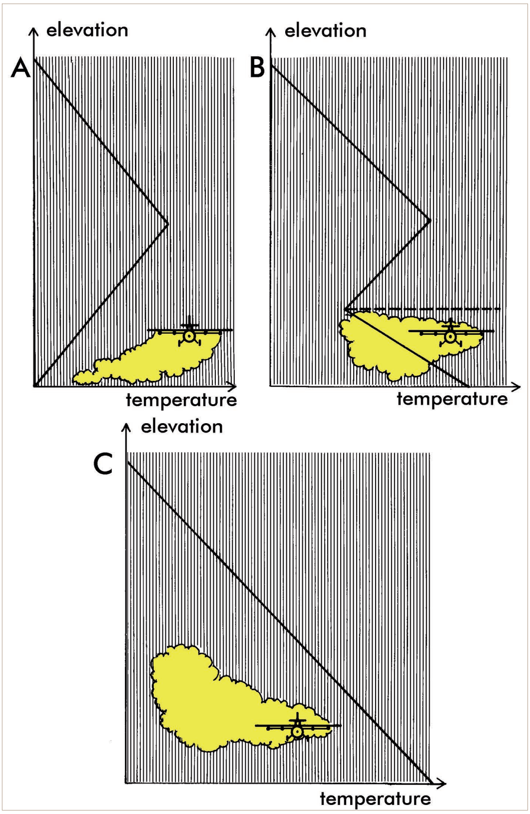


Figure 23. Air stability and its consequences on the quality of aerial spraying, in relation to thermal conditions (after Castel, 1982).

A: Inversion; air is stable, lateral wind is regular; good conditions for drift spraying.

B: Neutral conditions; inversion above; spray may still be acceptable.

C: Conditions of turbulences; air movements are unstable and upward; drift spraying should be avoided: droplets do not deposit on the target zone.

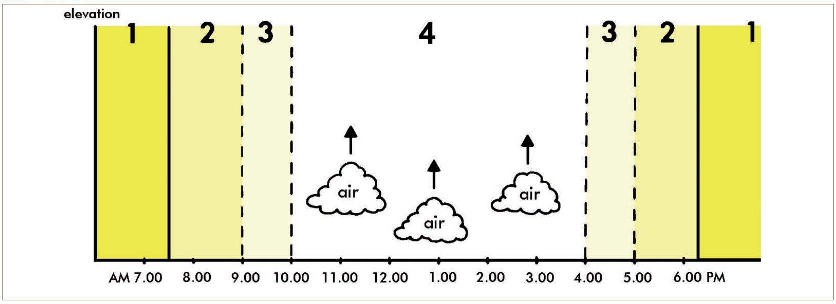


Figure 24. Periods suitable for controlled drift spraying, in relation to the daily variations of atmospheric stability (after Castel, 1982b).
1: period of inversion; usually suitable
2: period with rising temperature suitable for drift spraying
3: period with slight turbulences drift spraying still acceptable
4: period of strong turbulences; unsuitable for spraying

ULV formulations

Physical properties of formulations plays an important role in the quality of ULV spraying.
ULV formulations are oily and are generally supplied "ready to use".
Occasionally ULV formulation will be diluted with an oil adjuvant such as diesel oil to reduce the concentration of active ingredient.
The main physical properties of formulations which influence the spraying quality are:

1 - Specific gravity

The specific gravity of ULV formulations is generally between 0.9 to 1.2.

2 - Volatility

ULV spraying requires use of very small droplets. The surface area of small droplets is relatively large with respect to the volume. This implies that the rate of evaporation is higher with smaller droplets. If highly volatile solvents are used in ULV formulations, the evaporation from the small droplets would be high. The resulting droplets can very soon be in the aerosol range and might even become small dust particles that would stay suspended in the atmosphere. Therefore ULV formulations should be of low volatility to prevent loss of material through evaporation. For the same reasons water should not be used in ULV.

3 - Viscosity

Viscosity is defined as a fluids resistance to shearing. Viscosity is important for two reasons. The first is that viscous products are more difficult to pump and deliver through pipe work and orifices. Flow rates with highly viscous products can be low and inconsistent. Secondly high viscosity formulations can adversely affect droplet formation creating larger spray droplets. Therefore an ideal range for ULV formulation is generally between 5-30cP. The viscosity of a fluid is measured in units of a centipoise (cP). The thicker the liquid, the greater the viscosity and the higher the cP number.
When spraying a viscous formulation, the greater part of the volume is composed of large drops. Consequently, poor coverage is obtained, versus the

fluid formulations with which far better coverage can be obtained. Thus the viscosity has an influence on the spraying quality and it is an important factor to be considered for flow rate calibrations (tab. XII) and swath width, especially if it varies greatly with the variation of temperature.
The viscosity of formulations varies with the nature of solvent (tab. XIII) and the effect of temperature might be more or less important. The viscosity of water is 1 cP, that of technical Malathion is 45 cP.

Flow rate calibration should be done under temperature close to that under which treatments are executed. When writing purchase conditions, it is recommended to demand that physical properties should be clearly specified on the labels, because these data are needed for application officers to correctly make calibrations and for aircraft pilots to optimize loading ratio product/fuel.

Pressure (psi)	**Nozzle D 4 Fan 45**			**Nozzles D 6 - D 7**		
	Fenitrothion ULV 500 g/l	Fenitrothion ULV 1250 g/l	Diesel oil	Fenitrothion ULV 500 g/l	Fenitrothion ULV 1250 g/l	Diesel oil
40	1.29	1.36	1.48	2.05	1.76	2.20
50	1.48	1.57	1.66	2.36	2.20	2.45
60	1.62	1.78	1.82	2.58	2.32	2.75
70	1.80	1.95	2.02	2.84	2.60	2.68
80	1.89	2.03	2.15	3.08	2.80	3.10

Table XII. Flow rate of spraying system "Tee Jet nozzles" with different viscosities of oily formulations (litres per minute, after Castel, 1982b).

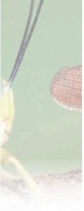
Liquid	**Viscosity (cP)**
Water	1
Pyrethroids	6 - 7
Dursban 1.5 ULV	12 - 14
Gas oil	28
Fenitrothion 500 ULV	4 - 6
Adonis 4 ULV	6
Adonis 123.5 ULV	5.6
Technical Malathion	30 - 40

Table XIII. Example of some liquid viscosity at 20° C.

Assessment of spraying

Necessity of assessing sprays

In most cases of poor control, the cause is usually attributed to product failure but more often than not the cause is due to poor application.
There are a variety of methods to check the application from checking the calibration and dosage applied is correct to checking the spray deposit in the field.



Droplets can be collected on oil sensitive papers or high gloss photographic paper with a dye added to the spray to aid in identifying spray drops.

Collecting droplets

Usually droplets patterns are fixed on artificial collectors where droplets leave permanent marks. There are different types of collection surfaces:

- glossy papers or coated glass plates;
- sensitive papers.

Using oil sensitive papers is simple and easy. The method does not require particular skill and the results are sufficiently reliable. Two types of sensitive papers are used: oil sensitive papers for ULV oil-based formulations and water sensitive paper for water-based formulations. Both might be supplied as rolls to be cut or ready for use cards (52 x 75 mm).

Oil sensitive papers

Oil sensitive papers are rigid black coloured papers coated with a thin white layer of oil soluble wax. When a droplet impacts the paper, the waxy surface is

Solvents and other carriers	Marking characteristics*
Benzine (car gasoline)	3
Castor oil	2
Cottonseed oil	2
Cyclohexanone	1
Dibutylphtalate	1
Diesel oil	3
Dimethylformacide	1
Dimethylphtalate	1
Dioctylphtalate	1
Ethanol	2
Hexylene glycol	1
Isophoron	1
Isoprpanol	3
Kerosene	3
Methanol	2
Methyltriglycol	1
Paraffin oil	3
Pine oil	3
Shelsol AB	3
Solvent 200	3
Soybean	2
Toluene	3
Trichlorethane	3
xylene	3

* 1: marks well 2: marks poorly 3: does not mark

Table XIV. Marking characteristics of solvents on oil sensitive paper CF1 (after Ciba-Geigy, 1994).

dissolved leaving permanent black marks proportional to droplet size. The impact diameter is always larger than that of the droplet from which it originated. The stain on the paper is related to the actual droplet size by means of the **spread factor**, i.e. the ratio of the stain size to the droplet size.

Unfortunately oil sensitive papers do not work with all ULV formulations as it requires a solvent to dissolve in and just using vegetable oil is not suitable. Actually marking property of a given formulation is not known. Thus it might be necessary to spray the paper, leave it to dry and check whether or not the black stain remains on the paper. Some carriers were tested for the marking characteristics on oil sensitive paper CF1 (tab. XIV).

Papers should be placed so that they could be impacted the same way as the target – usually positioned vertically on a rod or stick. To assess spray penetration, mark also upper, middle and lower position within the canopy. This process is also used to assess the swath width. Collecting droplets on sensitive papers requires good organization of successive operations:

- Sensitive papers should be handled with care. Do not rub them together or touch them with fingers or anything greasy, because the wax layer is very fragile and it is liable to be marked by wrong impacts.
- Sensitive papers should be numbered on the back before being fixed on supports (stakes).
- Sensitive papers will preferably be fixed on a wind vane or fixed on a plate positioned at 45-90 ° relative to the soil surface, a few centimetres above the foliage.

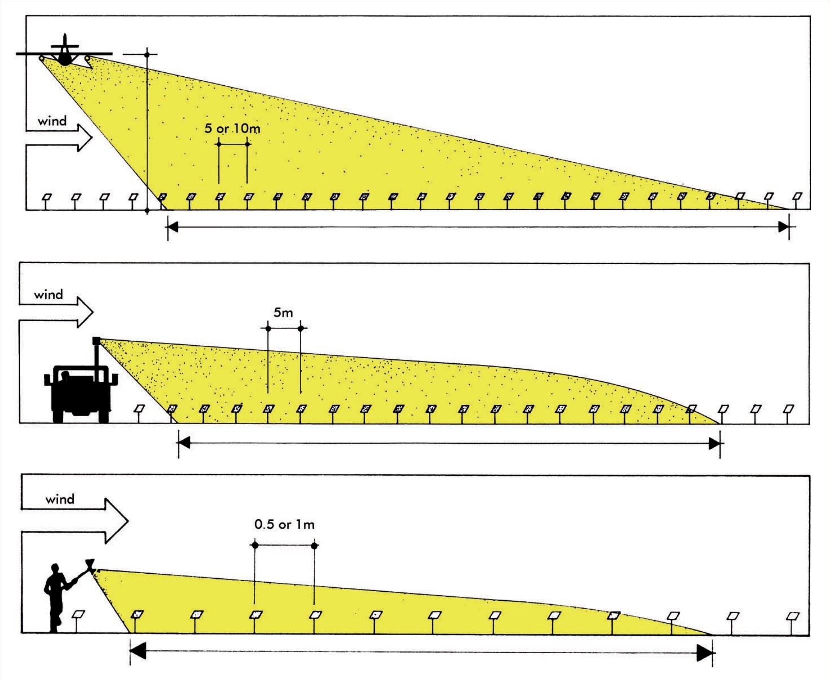


Figure 25. – Arrangement of droplet collectors for assessment of controlled drift spraying. Papers should be placed so that sensitive layer faces the wind.

Figure 26. Sensitive papers pinned directly within the canopy at different heights of a shrub like plant (after Ciba-Geigy).

- Sensitive papers will be maintained on their support by means of clothes peg, clips or rubber bands.
- Stakes should be placed so that the sensitive face of the papers faces the wind (fig. 25).
- If the target zone is covered with shrub like vegetation or bushes, spray penetration can be assessed by placing some papers in the lower, the middle and the upper position within the canopy (fig. 26).
- Collectors (papers and their supports) should be lined up facing the wind at right angle to the direction of the spray path (fig. 27). The distance between collectors depends on the sprayer type. Collectors will be placed every 0.5 m or 1 m on a distance of 50 to 100 m with hand-held ULV sprayers; every 5 to 10 m, on a distance of 100 to 200 m with vehicle-mounted sprayers. For aerial spraying, interval will be 5 to 30 m a minimum distance of 200 m, the maximum distance

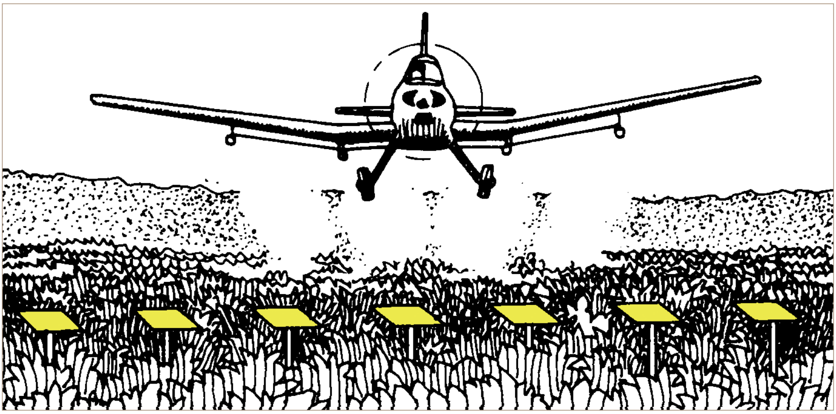


Figure 27. – Arrangement of droplet collectors aircraft spraying water-based formulation (after Ciba-Geigy). The papers are placed horizontally under the flying aircraft.

may attain 2,000 m (barrier treatment). The distance along which collectors are placed should equal, at least, twice the expected swath width.

- When possible two or three lines of collectors, separated by 100 m, should be placed.
- Spray should start at least 100 m before the first line of collectors.
- Under aerial treatment, wait a few minutes after the spray flight before picking up the papers, thus fine droplets will have enough time to deposit.
- For calibrations, a quick glance will give indications for targeting modifications. It may be possible to compare papers just after their impingement with standard cards with known VMD and droplet density (fig. 28).
- For thorough assessment, papers should be collected with great care and put away, each serial in a separate and labelled envelope. They will be stored with care for further investigations.

Water sensitive papers

Water sensitive papers have a coated yellow surface which will be stained dark blue by aqueous droplets impinging on it. Like oil sensitive papers they are fixed on rigid support or clipped directly to foliage of plants at different levels within the canopy.

On the site, after treatment, impinged papers might be compared with standard cards bearing known VMD and droplet densities (fig. 29) to estimate deposit and spectrum.

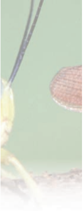
Some general guidelines on use of water sensitive papers are:

- When relative humidity is very high, only visual assessments can be done. Above 80 % relative humidity, papers will be over stained and thus will be unusable.
- When relative humidity is under 50 %, droplets smaller than 50 microns do not impinge on the paper because they evaporate before impacting it.
- Papers should not be used early morning if the crop is still wet with dew.
- When fixing the papers make sure the supports are dry.
- Before pinning up papers on their supports, it is recommended to number them.
- Papers should be handled with care and particularly not contacted with fingers or anything humid. When possible use clean, dry gloves.
- Supports should be driven into the soil every 2 or 3 m slightly above the soil surface or just above the foliage.
- If the object is to check the swath width and perform calibrations of the speed, the output should be done before droplet collecting.
- After impaction, papers should be collected only when dry and stored in an air tight container.

Analysis of oil and water sensitive papers

Analysis of oil or water sensitive papers can be made manually with a microscope and calibrated optics to size the droplets or using image analysis software. As droplets spread upon impact it is important to know the spread factor of the formulation used and also this will vary with droplet size.

For accurate spray assessments, like those required for insecticide experiments and evaluation of spraying equipment, it is necessary to determine the exact



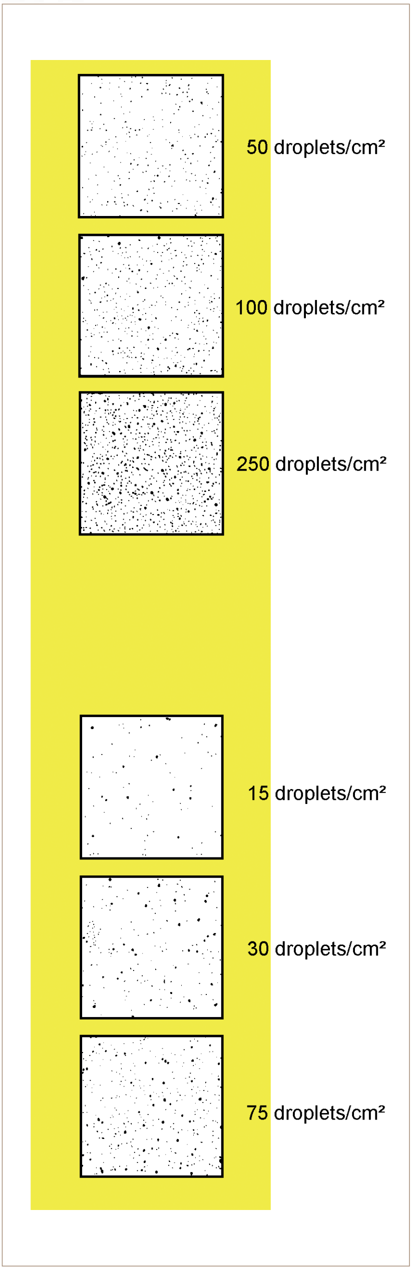


Figure 28. Standard cards for visual assessments of ULV spraying.

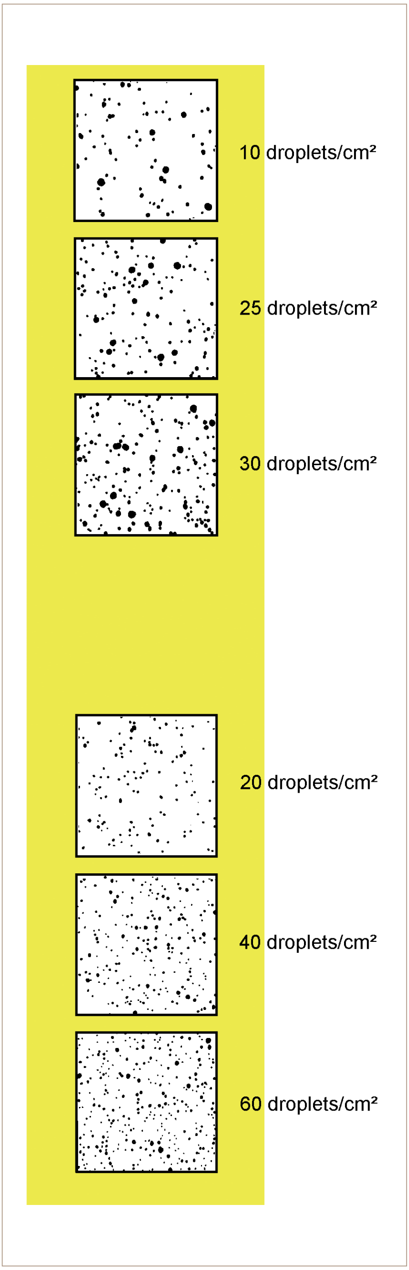


Figure 29. Standard cards for visual assessments of VLV spraying.

Formulations	Droplet size (microns)	Spread factor
Water-based formulations	< 100 200 - 400 400 - 500	1.7 2.0 2.1
Oil-based formulations	< 100 100 - 150 150 - 250	2.0 2.2 2.5

Table XV. Spread factor that can be used in the field, according to the formulation type and the droplet size (after Ciba, 1983 and Castel, 1986) .

spread factor of the formulation utilized. Collaboration with manufacturers is recommended to obtain this important data.

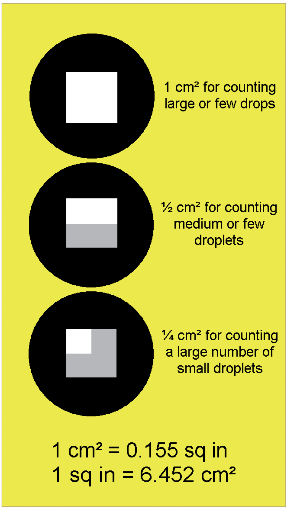
In most cases, using standardized spread factors enables to obtain quick and sufficiently liable results (tab. XV).

Image analysis

Generally, image analysis is made using a microscope equipped with a digital camera or scanner to capture images, and these are then processed by computer using image analysis software. This will calculate the range of droplet sizes by counting pixels on the digital image. Size can be expressed as VMD and the range expressed as VMD/NMO ratio or spa with a histogram printout. The number of droplets is often expressed as number per cm^2 and by inputting the concentration of active ingredient, the volume and dose per unit are derived.

Manual analysis

In most cases precise data are not required and then manual analysis could be performed, by means of foldable lens, portable microscope or binocular (magnification x 10 or 15) by using a droplet counting aid with standard windows of 1, ½ and ¼ cm^2 (fig. 30 and 31).



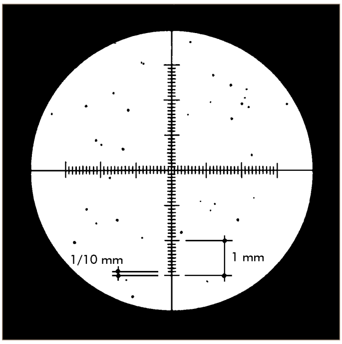
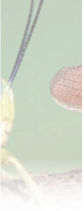


Figure 31. A view of micrometric lens for droplet counting and size assessment.

Figure 30. Card with standard windows for counting droplets (Spraying Systems).



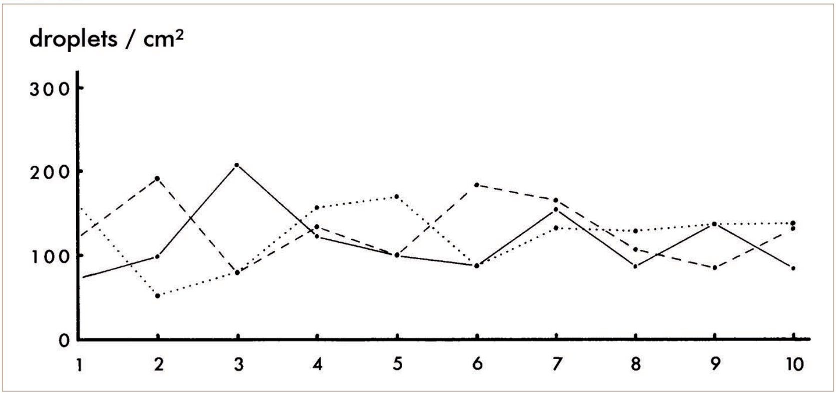


Figure 32. Droplet density profile on three plots treated with the same formulation and the same amount per hectare.
Experiments performed by CIRAD team in Chad in 1988 (3 l/ha of a ULV formulation applied by hand-held sprayer). Ten collectors were aligned in each plot.

Droplet density assessment

On each paper, four counts are made in different areas at random. When droplet density is high, use the smallest window (¼ cm²). The average number of droplets per cm² in each paper is calculated and recorded for further calculations. When all papers of all series are checked, then the average droplet density is calculated for all the papers (fig. 32).

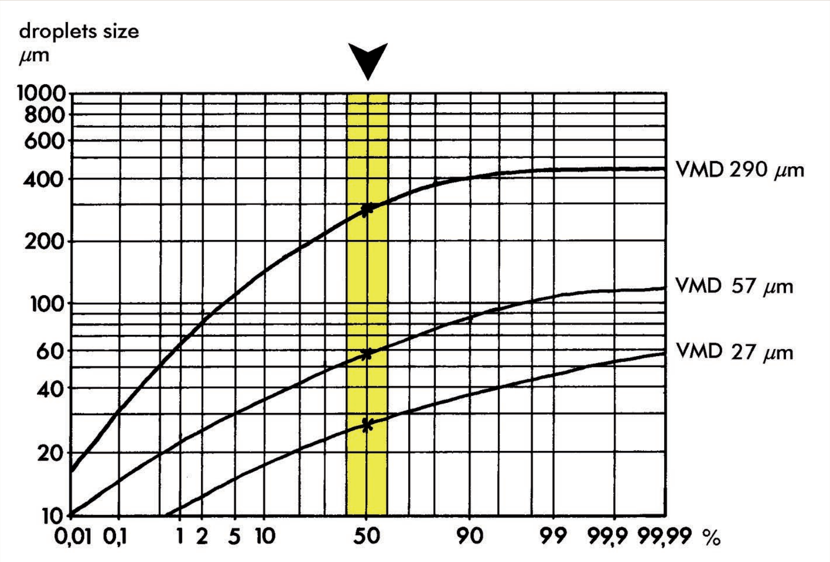


Figure 33. VMD manual determination (OEPP, 1982).

Droplet spectrum assessment

The VMD calculation requires sampling of at least 200 droplets and classifying them into regularly spaced size classes as a frequency distribution. Very large drops which are obviously out of the spectrum are discarded (leaking). Then the volumes are added together starting from the smallest volume and when 50 % of the total volume is reached the diameter of the drops at this median volume is the VMD.

It is possible to draw a curve of cumulated volumes and the VMD can be read at the interception of the curve and the vertical line starting from 50 % on the axis (fig. 33).

Half of the volume of the spray is composed of droplets smaller than VMD and half of it is larger than the VMD. This method is tedious to carry out and it is practically impossible to use on the field so, for common assessments, "$\mathbf{D}_{\mathbf{max}}$" method is accurate enough. The process for using D max method is as follows:

- Measure on each paper the two largest drops excluding those that are obviously out of spectrum i.e. those of which the immediate below class is empty.
- Then calculate the diameter of the five largest droplets belonging to the highest class. This value will be considered as D max.
- The VMD equals D max multiplied by the spread factor 0.45 is considered as an acceptable spread factor for usual ULV formulations.

The NMD is not assessed when D max method is used. This data is required only when it is essential to know the evenness of graticule i.e. for the evaluation of equipment or expedients of insecticides.

Spray distribution assessment

The objective of a spray is to ensure that droplets reach the vegetation in the target zone or the biological target itself. But it should be noted that it is very difficult to obtain an even distribution of droplets on the target zone and *a fortiori* on the biological target. Therefore a spray has to be considered thoroughly in order to decide what distribution in the field is required to achieve a sufficient biological and economical result with the concern of preserving the environment. Thus, in acridid control, the high mobility of the insects compensates to some extent, for unevenness in the spray distribution.

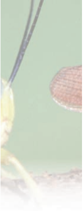
A visual assessment is possible by comparing visible deposit with standard cards which are subsequently calibrated by normal chemical methods.

The curve of a droplet distribution is helpful. The comparison of the resulting curve with standard curves may give an idea of the coefficient of the variation of droplet distribution. When accurate figures are required, it is more advisable to use statistical analysis. The following formula may be suitable:

Mean: $\overline{X} = \dfrac{\Sigma\, Xi}{n}$ **Standard deviation**: $\sigma = \sqrt{\dfrac{\Sigma\,(Xi - \overline{X})^2}{n-1}}$

Variation ratio: $CV = \dfrac{\sigma}{\overline{X}} \cdot 100$

Xi: droplet density (cm)
n: number of measures



The standard deviation and the arithmetic mean might be rapidly calculated when a programmable electronic calculator is available.

Practically an absolute even distribution virtually never occurs (variation ratio = 0). Actually in acridid control, important variation in spray distribution does not significantly influence the efficacy of acridicides. Moreover, barrier treatment with long residual activity insecticides may involve track spacing as wide as 2,000 m. In this case the evenness of the spray distribution becomes an unimportant factor.

Checking the swath width

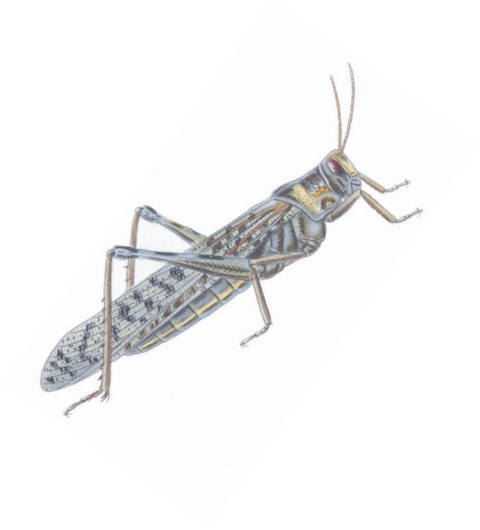
In acridid control a visual assessment with oil sensitive papers is often sufficient to show if the swath width is wide enough (see above).

If the swath width is shorter than expected, possible explanations include:

- In the case of large size droplets: the size should be reduced by adjusting the setting of the atomiser.
- In the case of good droplet size: the wind speed is too slow or the emission height is too low.

In contrast, if the collectors are impinged only by the side downwind, it means that the There is an overdrift which might be due to:

- Too low height of release or a strong wind. In this case the emission height should be lowered or, if not possible because it is already low, treatment should be postponed.
- Droplets of small size together with a narrow spectrum. In this case atomisers should be adjusted properly.



Spraying Equipment

FOREWORD

The types of sprayers which are designed for locust control are relatively few. Besides, each type of sprayer has specific and precise features which confer to its own originality. For this reason, an acridid control manual, designed to be useful to operators cannot preclude presentation of available equipment and must emphasize elements which might detract from their correct uses. The advice is based on the experience of operators and is restricted to acridid control. Equipment that seem of little use in acridid control might be excellent in another field of crop protection. It is therefore clear that comparisons made here are only aimed at helping operators to optimise the use of available equipment. The opinions expressed are solely those of the author at the time of publication and recommendations are likely to change as advances in spray technology occur. All companies quoted made useful contribution. It is possible that others, which are not presently known in acridid control, might deserve to be mentioned in the future. Registered trade marks are indicated in the text by capitals so that they may easily be recognised without being emphasized by, which should be considered as systematically implicit.

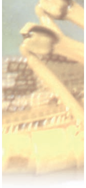
Portable equipment

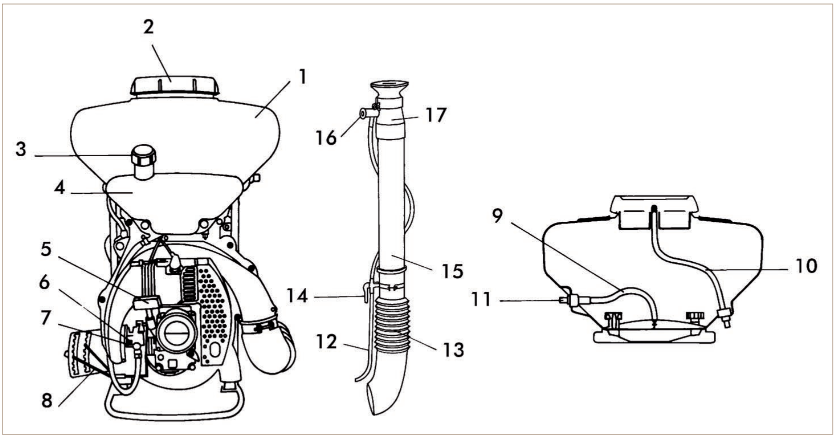
Motorized knapsack mist blower

In these devices (fig. 34) the air is a determinant factor for carrying droplets to the target. Droplets are generated by a blast of air which shatters a trickle of liquid into droplets. Some mist blowers are now equipped with a rotating device.

With sprayers of this type, it is possible to apply low volume (LV) of water-based emulsions. Those equipped with a good hydraulic circuit and a sound flow control valve can apply very low volume (VLV) of either water-based or oil-based formulations. For ULV spraying they should be equipped with a centrifugal apparatus which has a high rotational speed.

Considering their weight and bulk, the choice of knapsack mist blowers is relevant only when it is necessary to use the air blast for treating roosting locust on trees with a maximum of 10 m height. Mist blowers are also useful for treating thick bushes where locusts may hide.





1: pesticide tank
2: tank lid
3: fuel cap with gasket
4: fuel tank
5: handle for starter
6: throttle valve
7: fuel valve
8: throttle lever
9: hose back to tank

10: air pressure hose
11: insecticide outlet
12: hose tank to cock
13: hose to direct the air flow
14: on/off valve
15: rigid pipe
16: flow regulator
17: gas restrictor or Venturi

Figure 34. Arimitsu knapsack mist blower (Nigerian-Canadian Cooperation, 1987).

Description

The main constitutive elements of the knapsack mist blower are the structure, the engine and the circuits of the air and the liquid.

Structure

The chassis which is "L" shaped should be light and strong enough to support either the engine and the sprayer. It is designed so that the sprayer remains in vertical position when it is on a horizontal surface. To soften the vibration of the running engine, the chassis has rubber shock absorbers.

The straps and cushions are designed to ensure that the operator feels at ease when he carries the sprayer, which is relatively heavy. In fact, when it is empty it may weigh 14 kg and reach 24 kg when full.

Engine

The development of knapsack mist blowers is primarily linked to the evolution of the 2-stroke engine and the decrease of the material weight. Small capacity engines are light but powerless. Their stream is short and thus is not suitable for treating trees. Powerful engines have the capacity to run strong turbines which are capable of producing suitable streams for treating high trees and low crops when it is necessary to use an air stream to carry droplets. The rotational speed of the engine varies with models from 6,000 to 8,000 rpm. The rotational speed determines the velocity and the air flow. It is thus important to check it with a

tachometer. If the rotational speed is unsuitable, the engine should be calibrated or have it fixed at the workshop.

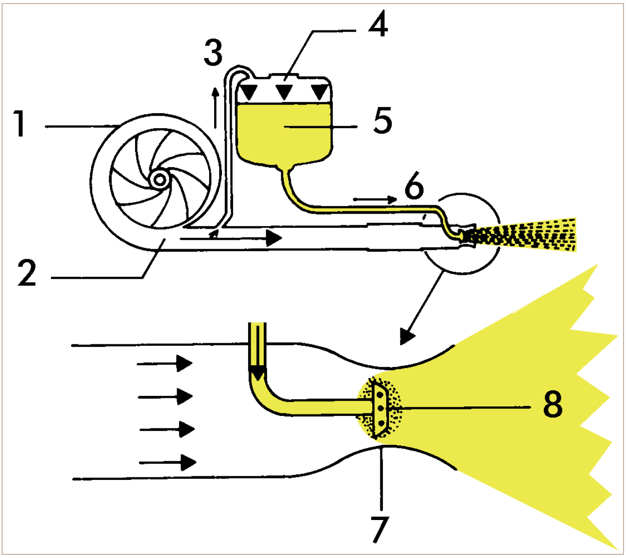
The fuel for 2-stroke engines is a mixture of oil (30 SAE viscosity) and two star petrol in 1 for 24 proportion. Multigrade oil should be excluded for this use.

These machines are usually equipped with a starting device, however it does not hold up well under heavy use. Therefore it is essential that a pulley should be present so that starting the engine, by means of a rope is possible when the return device is out of order.

For maintenance of the engine and moving parts, manufacturer's recommendations should be scrupulously applied. It is particularly important to ensure that, in all circumstances, cooling fins should be kept clean.

Air stream circuit

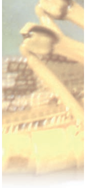
The air stream produced by the turbine is forced into a hose terminating in a restrictor (also called a Venturi) where the air stream and the product meet (fig. 35).



1: Turbine (producing high speed air stream)
2: Pipe where the air is pulsed
3: Hose for putting the liquid under pressure.
4: Under pressure tank
5: Insecticide flow to restrictor
6: Restrictor
7: Place where the air speed is the highest (Venturi)
8: Swirling place where a slight depression rises the flow of the liquid.

Figure 35. Operating diagram of a gaseous energy nozzle with detail of the restrictor (after Musillami, 1982).

When CDS is used, the hose is fixed in an upward position so that the operator's hand are free. Thus his attention is free to monitor his walking speed (fig. 36).



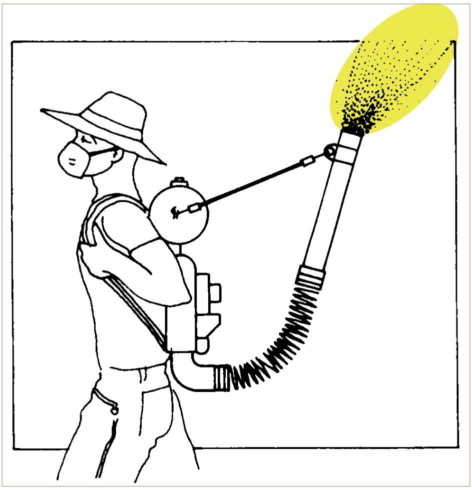


Figure 36. Note the position of the hose in such a manner as to allow the operator’s hand to be free and encourages individuals to focus on keeping a steady pace walking (after Matthews, 1985b).

Inside the Venturi is located in the droplet maker’s device. Since the re-emergence of locust outbreaks, some manufacturers have designed, with more or less success, centrifugal apparatus within the Venturi.

The liquid circuit

Tank

The insecticide tank, usually 10 l capacity, is made of plastic and has variable shapes. The filler hole is wide and equipped with a fitter, which should always be in place for filling. The cap includes a seal to ensure that the light pressure (0.2 bars) is sufficient for bringing the liquid from the tank to the restrictor. If the sprayer is equipped with VLV or ULV devices, a filter should be placed at the tank and the control valve.

Pump

Sprayers with centrifugal devices are also equipped with a small pump enabling a regular flow of the liquid, even if the gas restrictor is higher than the liquid in the tank.

Flow regulator

To ensure a good flow control, the flow control device should be placed between the tank and the gas restrictor. The device could be either a flow regulator or interchangeable orifice restrictors. Starting and stopping the spray is done by means of an on/off valve. VLV and ULV mist-blowers should always be equipped with a flow control valve accurate and easy to adjust. Particularly, it should be detached from the on/off valve. The progressive valves are not accurate enough to monitor small flows.

Spraying devices

Many brands and types of knapsack mist blowers are available in the market. During the last ten years, bilateral aids have made donations of many different brands

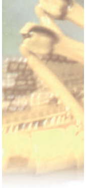
and types of mist blowers. This disparity also results in a diversity of spray heads from a plain hose which emerge onto the gas restrictor to centrifugal apparatus which rotate more or less rapidly.

Almost all manufacturers supply special nozzles to decrease the liquid flow, asserting that these devices are suitable for ULV spaying. However, since the principle of droplet generation is unchanged (gaseous energy), the droplet spectrum is too coarse to allow an acceptable ULV spraying. Some manufacturers got the idea, that is why they adopted centrifugal devices, with varying degrees of success. The main error committed is to enlarge the pipe head to install the rotating device which results in a dramatic slowing down of the air stream.

Adaptation of a rotating cage: Micronair AU8000

AU8000 atomiser of Micronair is designed to equip knapsack mist blowers, without important modification. This spray head of 1.5 kg, is composed of a rotary cage and a restrictor unit as a flow control. It is mounted in place of the gas restrictor (fig. 37).

Figure 37. Backpack mist blower fitted with AU8000 spray head (after Micronair). Power is supplied by the airstream produced by the mist blower. The hose might be positioned vertically for Controlled Drift Spraying.



The rotary atomiser is driven by adjustable fan blades in the air stream from the blower. The atomiser is fitted with a cylindrical metal gauze which produces droplets. If the air stream is strong enough to run the cage at 6,000 to 8,000 rpm, the droplet spectrum will be suitable for ULV spraying (fig. 38).

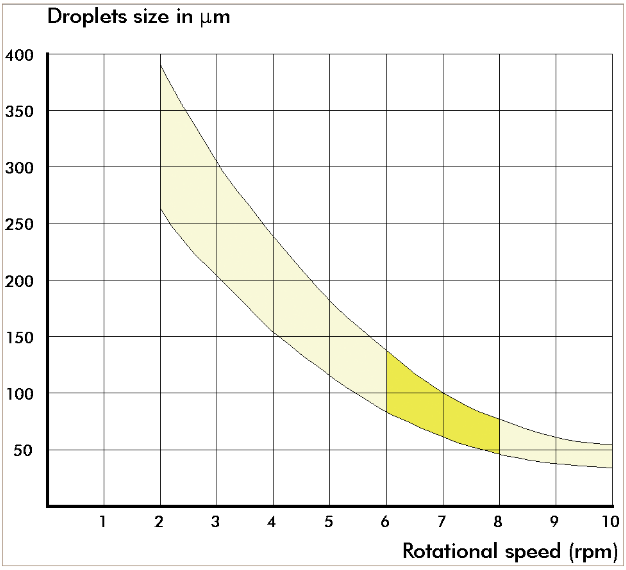


Figure 38. Variation of droplet size with the rotational speed of AU8000 Micronair cage (after Micronair, 1989).

The flow is controlled by the interchangeable restrictor tube attached to the on/off valve and by the chemical pressure. To facilitate flow preselection, the restrictor tubes are colour coded according to flow rates (tab. XVI). The indicated flows are given for water viscosity and thus are to be taken only as reference points for starting more appropriate calibrations. The procedure for flow calibration will be described in the next chapter.

Type of Micronair AU8000 atomiser		Flow (litre per min)
Number	Colour	
1	Brown	0.075
2	Red	0.150
3	Orange	0.300
4	Yellow	0.600
5	Green	1.200

Table XVI. Flow rate of AU8000 restrictor tube, measured with kerosene (after Micronair, 1989).

As well as being purchased with the complete sprayer, assembly, the AU8000 can also be supplied as a conversion kit for mist blowers, provided that they are

powerful enough, i.e. 5 HP machine, having minimal blower output of 20 m^3/min and air velocity of 125 m/sec at the outlet.
The size of the droplets produced by the spray head, depends upon the rotational speed of the atomiser and the viscosity of the chemical. The rotational speed of the atomiser depends upon the air stream produced by the blower and by the angle of the fan blades. As most mist blowers are designed to run at a fixed blower speed, the speed of the atomiser must be set by adjusting the angle of the fan blades.
To obtain a droplet spectrum which is suitable for ULV spaying, the rotational speed of the spray head should range between 7,000 and 8,000 rpm (fig. 39). The rotational speed can be checked by means of a tachometer. If there is no tachometer, a visual assessment of droplet size will indicate if the rotational speed needs an adjustment.

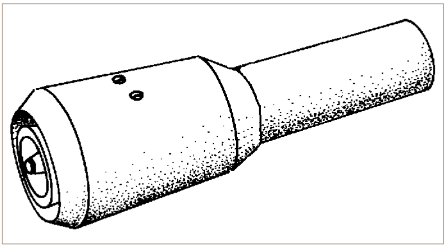


Figure 39. Micronex rotating cone for backpack sprayers (after Micron Sprayers).

Adaptation of a rotating cone: Micronex

This device can be adapted, with or without a bottle, to the airflow nozzle. The fan is activated by the air stream up to 12,000 to 16,000 rpm. The rotational speed depends upon the power of the engine.

The output might be adjusted from 30 to 100 ml/min by means of a set of colour nozzles. Droplet size can be adjusted by varying airflow or output. Droplet size might be decreased down to 40 microns.

This device produces droplets with fine and homogenous spectrum. However, when the mist-blower is not powerful enough, the flow rate is not very accurate, which necessitates maintaining the nozzle below the liquid level in the formulation tank. This constraint reduces the possibility of having the widest track spacing.

General functioning

The proportion of oil/gasoline mixture should be kept scrupulously. The filling up should be made through a fine mesh filter by means of a funnel to avoid spilling gasoline over the engine, because it may spontaneously catch fire when it is very hot. After the filling up the filter cap should be replaced carefully.

To start the engine, follow carefully the procedure indicated by the manufacturer. While spraying, the engine should run at full speed for only short periods.

When the sprayer is equipped with only a gaseous energy nozzle, it should be noted that with a constant liquid flow, a diminution of the air flow will result in a rising of droplet size. For a given air flow, an increase of the liquid flow will have the same effect.

Hand-held ULV sprayers

At he beginning of the 1960's, the necessity for reducing the volumes of application, led to the development of hand-held ULV sprayers, which are operated by torchlight batteries, R20 type. In 1975, several hundred thousands hectares of cotton were already treated by this sprayer in Western Africa (Cauquil, 1987). As they are simple and strong and because they need no water or just a small amount, they rapidly replaced the knapsack hydraulic sprayers among cotton growers. Their success was amplified by the need for frequent applications and the availability of less toxic insecticides such as pyrethroids.

From 1985, hand-held ULV sprayers started to be used in acridid control, particularly against grasshoppers. Now, beside cotton, they are commonly used in tropical zones on food crops such as tomatoes, rice, maize, groundnut, millet etc.

Hand-held sprayers may play an important role in acridid control, particularly for close protection of food crops and whenever farmer participation is necessary for technical or social reasons. At the onset of the rainy season in Sahelian countries, controlling the first hatching of grasshoppers may be critical in preserving the seedling. Although grasshopper pullulations may develop into plague, it is not conceivable to expect that National Plant Protection Services will respond everywhere to everybody at the same time. Where, formerly, dusting bags were used, hand-held sprayers will advantageously be a substitute. Besides, chemical companies have now introduced many special formulations for use with this type of sprayer, which can be used either with water or oil based sprays. However it should be recommended that those formulations, be of low toxicity to human.

Description

The constitutive elements of hand-held sprayers are the tubular handle, the head locking sleeve, the electric motor, the energy source, the bottle, the tank and the atomiser disc (fig. 40). They are relatively light weighing around 1.7 to 1.9 kg.

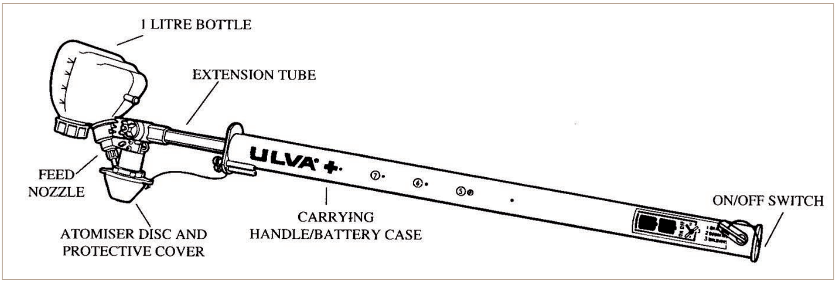


Figure 40. Layout of hand-held ULV sprayers (after Micron Sprayers).

Tubular handle

The handle has several roles: casing the batteries, varying the droplet emission height, handling the sprayer. At the bottom, there is the on/off switch. Most of hand-held sprayers are now equipped with a telescopic lance made of aluminium. The battery case is made of plastic (Berthoud) or aluminium (Micron Sprayers). C5 of Berthoud contains 5 batteries and Micro Ulva+ of Micron Sprayers, 5 to 8.

Head locking sleeve

The head locking sleeve is made of plastic or metal. It enables the setting of the head angle to the extension tube so that the nozzle axis is maintained at vertical position, according to the emission height.

Electric motor and energy source

The motor is placed in a sealed plastic housing. It is powered by torch (D-cell/R21) batteries under a voltage which varies from 6 to 12 volts, with the number of batteries. The disc is thus denticulate at 4,000 to 10,000 rpm and the highest speed is used for ULV treatment while the slowest is for water-based applications including herbicides.

Most of models have a fixed rotational speed while Micro Ulva+ models may run at different rotational speed according to the number of batteries inserted in the case (tab. XVII).

Number of batteries*	Rotational speed (rpm)	Droplet size (microns)	Flow (ml/min)
2 (3 volts)	3,000	110 - 130	100
4 (6 volts)	7,000	70 - 90	60
6 (9 volts)	11,000	50 - 60	40
8 (12 volts)	15,000	35 - 45	20

*1.5 volt R20 type batteries.

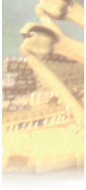
Table XVII. Droplet size against flow rate and rotational speed of the disc for the Micro Ulva+ (after Micron Sprayers).

Consumption of energy and the wearing out of batteries depend upon the consumed power and the efficiency of the motor. Some motors consume more energy than others. The way of working also has its importance in the batteries wearing out. Thus, after a working period, the voltage decreases. Normally, after a rest period, a repolarisation occurs with a voltage recovery. Hence, it is recommended to alternate five minutes rest with twenty minutes of continuous spraying.

Whenever possible, it is better to use alkaline batteries than saline, because the latter are less efficient and less resistant to intensive use.

Bottle and additional tank

The bottle, 1 litre capacity, is made of translucent plastic. This low capacity is not tyring for operators. The sprayer, with 1 litre of product in the bottle and loaded with 8 batteries, weighs approximately 2.5 kg. The bottles are calibrated, some with 0.250 l graduations others 0.200 l graduations, which enables the operator to check the variation of the product level in the bottle. If required it is possible to add more graduations by waterproof ink.



Some models of sprayers have a filling hole independent from the neck (fig. 41) in addition to a refilling point that can be connected to an additional tank. All are designed to ensure an introduction of air in the bottle, thus enabling a regular flow of the product.

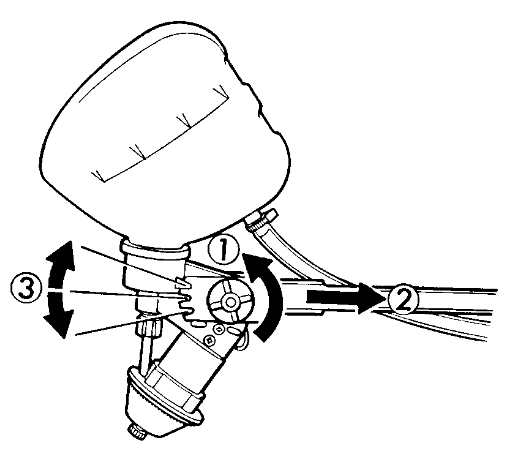


Figure 41. Diagram of the head of a hand-held ULV sprayer (after Micron Sprayers). The spray head can be adjusted so that the feed nozzle is as close to vertical as possible.

Most of manufacturers now supply a backpack tank to be used for refilling directly the bottle fitted with the spray head. This tank is connected to the bottle by means of a hose and an on/off valve. Transferring the product from the tank to the bottle is carried out by placing the base of the bottle on the ground and opening the valve.

Nozzles

Manufacturers provide with each model a set of coloured nozzles with different diameters corresponding to different flow rates.

It should be noted that the same colour does not correspond to the same diameter of sprayers from different manufacturers. So, it is recommended to refer to the instruction manual for identification of nozzle diameters. It is advisable that manufacturers use the same colour for the same diameter. Usually, nozzles can be changed without using any tools.

Tables of flow rate given by the manufacturer are measured with water and sometimes with surfactant. They are only to be taken as an indication for more accurate calibrations. ULV formulations have different viscosities and should always be measured before spraying a new product.

Atomiser discs

There are different shapes of discs: dish form with a curved rim and more or less open cup, 50 to 80 cm diameter. They are fixed on the motor axis by a clip or a screw. They all can be replaced if they are damaged. All sprayers are provided with a protective cover to prevent discs from impacts.

Berthoud		Micron Sprayers	
Nozzle colour	Flow rate	Nozzle colour	Flow rate
Violet	25	Red	90
Blue	45	Black	150
Yellow	85	Grey	175
Red	100	Pink	195
Green	150		
Black	200		

Table XVIII. Flow rate of two different hand-held sprayers for water-based formulations (after Berthoud and Micron Sprayers).

Disc rim may be denticulate or smooth. Denticulate discs produce the narrowest droplet spectrum, however they are more fragile.

Functioning of hand-held sprayers

Liquid is fed by gravity through a nozzle to the disc centre and the centrifugal force spreads the liquid as explained in the preceding chapter. For a given viscosity, droplet size varies with the rotational speed and the flow rate (tab. VII).

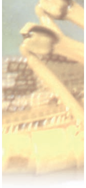
Vehicle-mounted sprayers

Until the late 1980's, only the exhaust nozzle sprayer (ENS) was available as the vehicle-mounted sprayer. Introduction in the market of electrical vehicle-mounted sprayers was considered as notable progress since the electrical energy does not affect the motor of the vehicle. Since then, they were being improved under the constraints of rough working conditions in desertic zones.

Vehicle-mounted sprayers are dependent, more or less closely to the vehicle. The most dependent is the exhaust nozzle sprayer since it is entirely submitted to the power of the vehicle (volume and the stream of exhaust gas) for producing droplets. The mechanic specifications of the vehicle are also very important for forward speed. Some are autonomous. They are only dependent upon the vehicle speed, since they have petrol or gas oil engines as their own source of energy (Micronair AU8115 of Micron Sprayers, Puma and Super Puma of Berthoud). Electric-mounted sprayers are free from the vehicle power for producing droplets but they depend upon its source of electricity and the accuracy of the dose is related to the variation of forward speed (Ulvamast of Micron Sprayers). The L15 of Curtis Dyna-Fog is dependent of the vehicle source of electricity but, thanks to its radar *Syncroflow*, the accuracy of the dose is free from the vehicle speed.

In 1988, FAO published guidelines on minimum requirements for agricultural pesticide application equipment. Regarding vehicle-mounted sprayers, hereinafter the main requirements:

- The sprayer unit should be securely attached to the vehicle platform.
- All handles, grips or hand holds should be at least 300 mm from a hinged joint.
- Ideally a vehicle-mounted sprayer should be fitted with a closed transfer filling system for chemical. However, where filling is manual, it should be possible to add the chemical to the tank with the operator standing on the platform.



- Reach distance for filling should not exceed 1 m vertically from the platform and 0.3 m horizontally from the body of the person pouring the chemical. This pouring zone should be free from obstruction.
- The sprayer tank(s) filling system must permit safe, easy filling without overflowing or splashing at a specified maximum filling rate.
- All external parts of the sprayer should be designed so that liquid is not retained on the surface of the machine and any chemical residues which accumulate can readily be washed off by a practical cleaning routine which should be defined in the sprayer manual.
- There should be no sharp edge, abrasive areas or sharp projections which could cause physical injury.
- The sprayer should be stable when free standing and should remain upright when positioned on a 1 in 10 slope in any direction and irrespective of the amount of liquid in the tank(s).
- Adjustment to the sprayer, routine maintenance, drainage and cleaning should be easy carried out without the use of specialised tools.
- The manufacturer should provide a clear, illustrated, instruction manual in accepted commercial language for a specific market or in English, French or Arabic, etc.
- The manual should contain procedure for:
  - initially assembly,
  - identification of all spare parts,
  - setting and calibration,
  - cleaning and decontamination,
  - routine maintenance and storage,
  - safe and efficient use of the sprayer,
  - minimising risks to the operator and the environment associated with all aspects of machine use including spray drift.
- The manufacturer should also provide information on:
  - nozzle selection,
  - the maximum nozzle size and operating pressure to be used,
  - the handling of undiluted,
  - pesticide formulation during mixing (if required) and filling,
  - procedures for minimising the need for disposal of unused spray liquid, rinsing and washing water,
  - procedures for the safe disposal of any dilute pesticide,
  - any protective clothing requirement consistent with pesticide label recommendations.
- The sprayer should be clearly and durably marked to indicate the manufacturer's name and address, sprayers name and model and should indicate the year of manufacture.
- The manufacturer should provide evidence to the purchasing agency that a practical system is in place to record the machine specifications, make, model and year of manufacture so that spare parts can be accurately specified for a minimum of five years after the date of manufacture.
- All controls should be easily reached by the operator in the normal working position.

- All parts of the sprayer should be made from material which are non absorbent and unaffected by approved pesticide formulation and those parts which are exposed to sunlight should be made from materials do not degrade in UV light. The relevant information on material should be made available to the purchasing agency by the manufacturer.

Vehicle-mounted autonomous sprayers

Except for forward speed these sprayers are independent from the vehicle. The required energy is provided by an auxiliary thermal engine. In most cases they are air carrier sprayers where droplets are produced by any process (gaseous, liquid pressure or centrifugal force or a combination of two).
Some of this sort of sprayers are enormous and are equipped with 50 HP thermal engines carried by tractor (fig. 42) or by lorry (fig. 43). Even if these big sprayers produce an acceptable droplet spectrum, their weight and the constraint imposed by their maintenance make them unsuitable to current uses in acridid control.

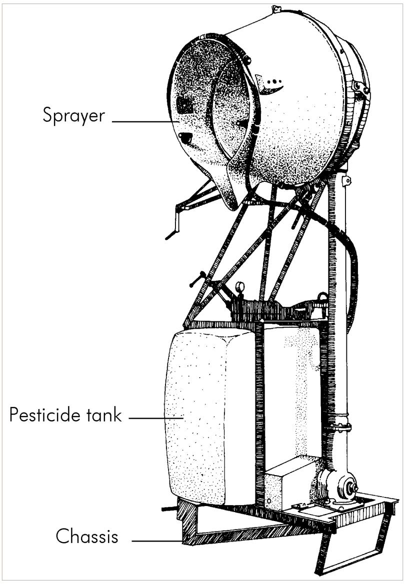


Figure 42. Air carrier sprayer carried by tractor (after Tecnoma, 1988). This type of sprayer can be useful to control locust adults when they are roosting on high trees.

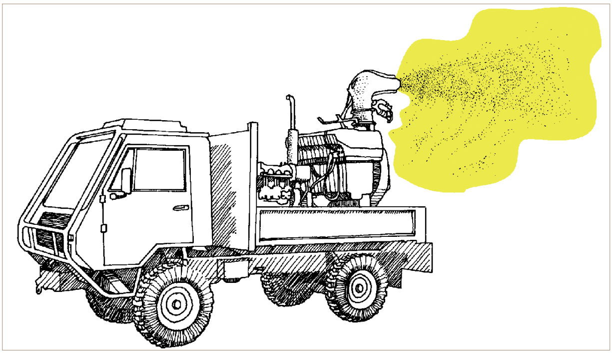


Figure 43. Air carrier sprayer on a small 4-wheel drive lorry (after Berthoud, 1988). This type of sprayer is powerful but very difficult to handle and to maintain in usual acridid control conditions.

In contrast, small and compact sprayers that can put on the platform of any four wheel drive pick-up, may be suitable provided they generate a droplet spectrum fine enough to comply with ULV specifications.

Puma air carrier sprayer of Berthoud

The Puma air carrier sprayer is a compact set assembled on a steel chassis. It is fitted with an 85 l polyethylene tank, a centrifugal pump with a filter; an air steam pipe which can be set in various positions from horizontal to vertical, owing to a 45 degrees articulation (fig. 44). The energy is provided by a diesel or a gasoline engine). The diesel engine, 8 HP, is equipped with an electric starter while the gasoline motor may have electric or mechanic starter (pulley and rope). It is possible to control the spraying from inside the cab. The sprayer set weighs 94 kg with gasoline engine and 128 kg with diesel engine. It is equipped with straps with which it can be held on to the platform and transferred to another vehicle or unloaded. If necessary, it is possible to fix it to the platform with bolts and nuts.

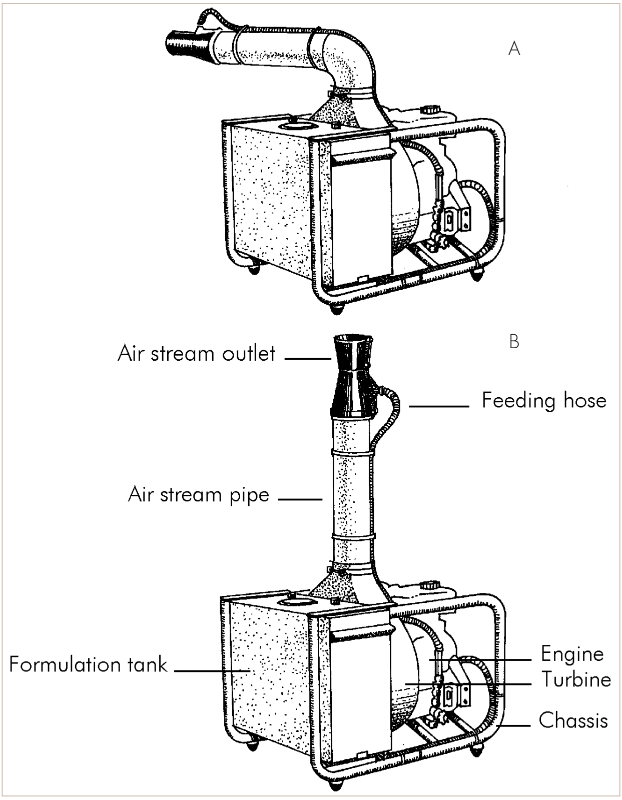


Figure 44. The Puma sprayer set showing an articulation, enabling the vertical position of the air stream outlet. The air stream pipe might be horizontal (A) for air carrier spraying or vertical (B) for controlled drift spraying.

The Puma set is a pure gaseous nozzle and is fitted with a fan turbine which generates an air stream of 1,350 m^3 with a speed of 408 km/h. Normally with these specifications it is possible to generate droplets having a spectrum good enough to accomplish correct very low volume applications.
The flow rate is calibrated by a combination of perforated plates, coloured nozzles and a variable flow restrictor (tab. XIX). That allows a very wide range of flow rates.

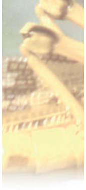
Flow restrictor	Orange nozzle 8/10	Red nozzle 10/10	Green nozzle 12/10	Blue nozzle 15/10	Grey nozzle 18/10	Black nozzle 20/10	White nozzle 25/10	Violet nozzle 30/10	Free
1	0.29	0.33	0.51	0.68	0.80	0.90	0.95	1.00	1.05
2	0.30	0.33	0.52	0.72	0.90	0.98	1.20	1.30	1.55
3	0.30	0.34	0.53	0.77	0.95	1.10	1.40	1.60	2.10
4	0.31	0.34	0.54	0.79	1.00	1.20	1.61	2.10	2.80
5	0.31	0.35	0.55	0.80	1.05	1.25	1.85	2.55	3.15
6	0.32	0.35	0.56	0.85	1.15	1.30	2.00	3.05	4.00
7	0.32	0.35	0.57	0.90	1.24	1.41	2.15	3.25	4.80
8	0.33	0.36	0.58	0.95	1.25	1.56	2.20	3.25	5.20

Table XIX. Example of flow rate variation of water with a Puma sprayer set, equipped with a 4 mm plate and different coloured nozzles (after Berthoud, 1999).

This type of sprayer may be useful in Saharan-Sahelian zones where it is sometimes required to alternate air carrier and drift treatments.
The Puma sprayer set is compact and relatively strong. It may be carried by a small pick-up, provided it is four wheel drive. It is a completely autonomous and thus it may be quickly transferred from one vehicle to another with minimal tools. However it suffers from constraints linked to the maintenance of thermal motors and its droplet spectrum is relatively coarse.

Micronair AU8115

This sprayer is designed to use the Micronair AU8115 spray head which uses rotary atomisation. It is self-contained and is designed for a wide range of applications including acridid control. The entire sprayer is mounted in a frame and is ready for installation in the rear of any four wheel drive vehicle. It may be necessary to make some adaptations to suit certain vehicles.
The sprayer may either be permanently bolted to the platform of a vehicle or may be temporarily secured if it is not to remain on the same vehicle all the time. For permanent installation, the frame can be bolted directly to the vehicle platform or bolted to wooden cross-beams which are in turn bolted to the vehicle platform.
For temporary installation, the sprayer is secured to the vehicle by means of suitable straps passed through the top corners of the frame.



Components

Engine

It is an 11 HP air cooled 4 stroke petrol engine, powerful enough to allow derating for high temperature and altitude conditions. The engine is fitted with a rope pull recoil start mechanism. The engine is selected for the worldwide availability of spare parts.

A handbook is available from the manufacturer, which explains running procedures and safety instructions. They are important and should be scrupulously followed so as to avoid any malfunction or accident.

Airstream system

The blower unit is directly coupled to the engine crankshaft. It generates a high velocity air stream which is led to the spray head through a flexible air duct.

Spray head

Air driven AU8115 atomiser is mounted in an adjustable swivel which allows the variation of air stream direction. An optional extension kit is available to allow the spray head to be raised up. Thus the release height may attain 15 metres. This possibility is particularly useful when wide swaths (100 m or more) are required or for treating tall crops such as sugar cane or corn.

AU8115 atomiser is built from chemical resistant materials. To ensure a long period of trouble-free performance it should not be mistreated and cleaned after use. The spray head is dynamically balanced to ensure it will rotate smoothly without vibration. Some chemicals, particularly certain solids in suspension or ULV formulations, can dry or crystallise on the gauze, blocking the mesh and causing the atomiser to vibrate. this can easily be avoided by spraying 1-2 litres of liquid from the atomiser at the end of each spray job. The liquid must be a solvent for the chemical which has been used. Water will normally only dissolve water-based formulations. Kerosene or diesel fuel is suitable for ULV products. The bearings of the AU8115 are sealed and lubricated for life. They should be replaced if they become worn.

Chemical feed system

It is composed of a tank, chemical valves flow control valve and the filter.

Tank

100 l capacity tank UV stabilised high density polyethylene. 5 l graduations.

Pump

Magnetically coupled centrifugal pump.

Adjustments and calibrations

Droplet size

The atomiser is driven by the high velocity air stream generated by the blower. To meet the required droplet size, the atomiser is fitted with fan blades of which the angle can be adjusted according to the flow rate and the viscosity.

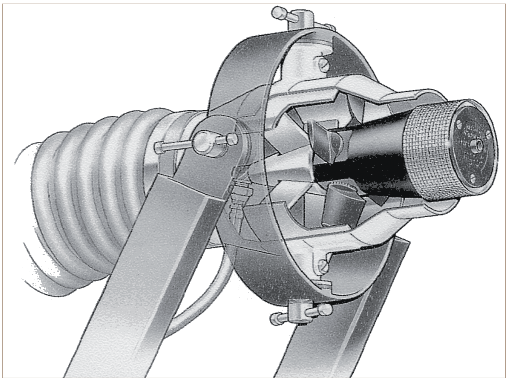


Figure 45. Micronair AU8115 spray head (after Micron Sprayers). The spray head is double axes articulated.

The higher the speed of rotation, the smaller the droplets (fig. 46). A fine blade angle (corresponding to a smaller setting number) gives a high rotational speed (fig. 47). The procedure to change the blade angle is shown by manufacturer in the operator's handbook. It should be followed scrupulously. It should be noted that all the four fan blades must always be set to the same angle.

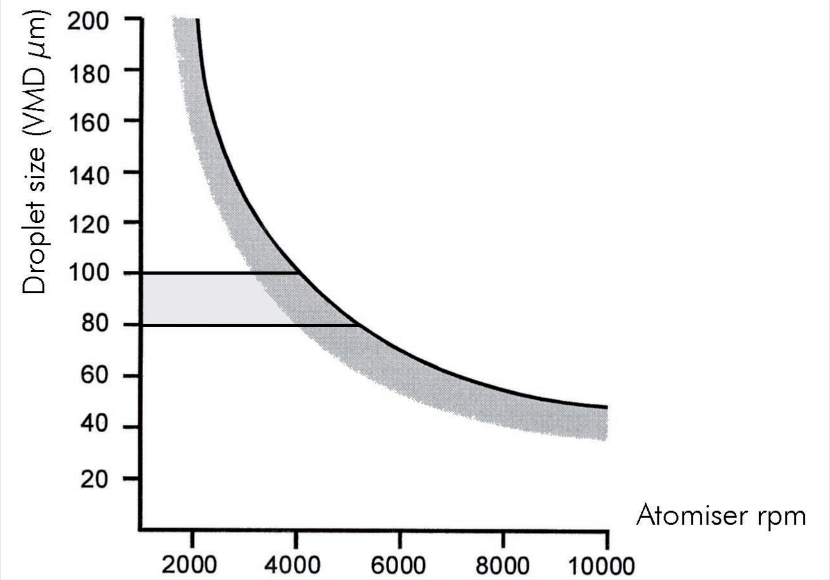


Figure 46. Spray droplet size against atomiser rotational speed (after MicronSprayers).
The most suitable rotational speed for acridid control ranges from 4,000 to 5,000 rpm.
All measurements were made with water, hence the indications are given as basis for further calibrations to be made with actual formulation.

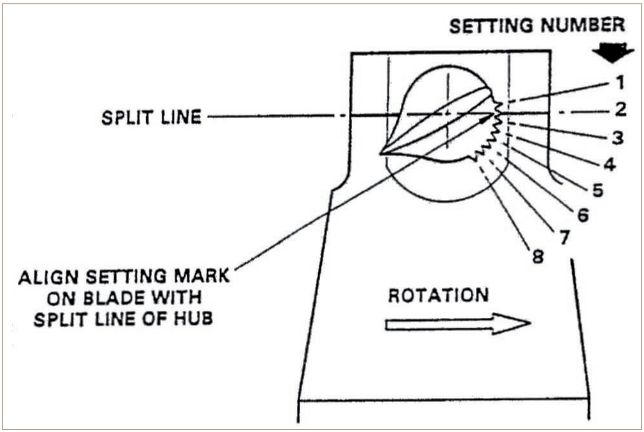
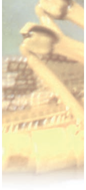


Figure 47. Procedure to change the blade angle (after Micron Sprayers).



The droplet size can be adjusted from around 45 to 300 microns VMD. For acridid control, a range of droplet size from 30 to 120 microns (for a VMD around 90 microns), is suitable for an acceptable control whereas, a range of 100-175 microns is required for VLV and LV in general agricultural applications.

Flow rate calibration

The flow of chemical from the spray head is controlled by the variable restrictor unit (VRU) in the feed to the atomiser and by the chemical pressure. The knob of the VRU is marked with odd numbers 1 to 13, around the outside and even numbers on the end. VRUs supplied with AU8115 atomisers are fitted with low numbered "L" plates with holes 1 to 7 (tab. XX). Therefore the VRU should be set by aligning one of the numbers 1 to 7 with the line on the VRU body. The numbers 8 to 14 are not used on standard VRUs supplied with this atomiser and should be ignored.

VRU setting	**Pressure**			
	0.66 bar (10 psi)	1.0 bar (15 psi)	1.3 bar (20 psi)	1.7 bar (25 psi)
1	0.22	0.27	0.32	0.36
2	0.36	0.44	0.60	0.66
3	0.60	0.84	0.96	1.00
4	0.82	1.00	1.20	1.30
5	1.00	1.28	1.48	1.68
6	1.34	1.64	1.88	2.14
7	1.74	2.20	2.52	2.88

Table XX. Approximate flow rate for AU8115 atomiser fitted with VRU with low "L" plate, in l/min (after Micron Sprayers, 2000).

Should an unrestricted flow be required, the VRU can be set to the full flow position by turning the thimble to number 7, pulling it back and rotating through 90 degrees until it locks the outward position. This separates the two plates and provides an uninterrupted flow. To release the unit from the full flow position, turn the knob in either direction until the spring returns the selector plate to the normal position. It is advisable to push down on the knob with the palm of the hand to ensure positive seating. Should the unit become blocked after the selecting of the full flow position, it can sometimes be cleared by turning the selector plate backwards and afterwards. Any contamination between the plates will hold the plates apart and give an irregular output.

General maintenance

After use drain any remaining chemical from the tank. Any unused chemical must be collected in a suitable container for future use or safe disposal. A short length of flexible hose connected to the outlet of drain valve will help to avoid spillage whilst draining the tank.

It is very important that the entire sprayer is flushed out and cleaned after use. Many ULV formulations are corrosive and aggressive and could damage the sprayer if they remain in the system for a prolonged period. The system should be

flushed out by spraying a suitable solvent for the chemical which has been used. This should be done at the spray site so as to avoid the risk of contamination of an off-target area by dilute chemical. Any solvent remaining in the tank should be drained and disposed of safely. After flushing all external surfaces should be washed with a suitable solvent followed by warm water (whenever possible) and detergent.

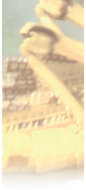
Under any circumstances should any chemical or cleaning solvent be left in the sprayer when it is not used.
For more specific maintenance, the supplier provides, with each sprayer, an operator's handbook and catalogue, in which the procedure is thoroughly explained.

Vehicle-mounted electrical sprayers

These sprayers work under a voltage of 12 volts and a strength of 10 amperes as a maximum. This low requirement makes it possible to connect them to the electric circuit of the vehicle.
The originality of these sprayers lies in their relative lightness (about 65 kg), their compactness and small need of energy. They can execute correct spraying even when they are fixed on relative powerless vehicles, provided that they are four wheel drive. Their connection and functioning are simple. The battery is not affected since the sprayer is not often run while the vehicle engine is stopped.
These sprayers were proposed for locust control during the late 1980's. They are rustic, low energy users and easy to use, which give advantage for taking advantage in acridid control, especially in preventive locust control where they could be an interesting alternative to the exhaust nozzle sprayer (ENS).
The basis calibrations of theses sprayers will be described in the next part (part Acridid control treatment).

Components

The frame and the mast
The sprayer frame is usually made of galvanised or coated steel and it supports a folding mast. This bears the spray head and sometimes allows a little variation of emission height.
The liquid circuit
The liquid circuit comprises the insecticide tank (and sometimes a flushing tank), the pump, an isolation valve, a drain valve, the flow control mechanism, filters and hose pipes. These materials are more or less resistant to corrosion.
The electrical circuit
The electrical circuit comprises nylon protected electric cables, the connecting system to the battery and the control box which can be placed in the cab, within the reach of the driver's hand.
The spray head
The spray head bears a centrifugal-energy nozzle. It uses the electricity provided by the alternator and taped from the battery.



Installation

The vehicle on which these sprayers are to be mounted, must have an enclosed cab with all its glasses so as to protect the driver from the spray. The sprayers should be positioned on the platform, as far as possible to rear of the vehicle so that, when the mast is extended, the atomiser projects outwards beyond the back of the vehicle. This position also spare a place to additional load of insecticide especially during preventive control operations during which survey and spray alternate and facilitate draining of the insecticide tank.

The sprayer should be rigidly secured to the vehicle via holes drilled in the platform floor using appropriate foot plates, bolts, washers and nuts usually provided by the manufacturer. It should be taken care to avoid the vehicle fuel tank (which is usually beneath the platform), when drilling holes. For a temporary installation, the sprayer can be tied down to the platform with ropes or straps secured around the frame. It should be noted that this installation is possible only when the land is not very rough.

The alternator of the vehicle provides the energy and the connection is made to the battery terminals. The connecting system should be easy to install and easy to disconnect and provided with cutout device. The electrical cables should be protected in a conduit which is resistant to heat and to chemical corrosion. It also should be long enough to allow the control box to be located in the cab of the vehicle, within the reach of the driver's hand.

When installing vehicle-mounted electrical sprayers, special care should be taken:

- If the sprayer is equipped with a remote control system, the cable should be fed through a clearance hole in the vehicle chassis and the reconnected. When drilling clearance holes, ensure that all sharp edges are removed and covered to prevent premature wearing of the remote cable. When routing the cable to the vehicle cab, make sure that it is not exposed to any sharp edge and avoid any sharp bends. Once the cable has been routed to the cab, reseal all drilled orifices to prevent spray mist or exhaust gases from entering the cab.
- Before proceeding with any operation, the operator should be thoroughly familiar with starting and stopping the machine and with all the operating controls.
- Before full operation, exercise the machine through its full operation sequences from a position of full visibility.

Ulvamast

The first model of the Ulvamast sprayer (fig. 48) was designed upon the basis of the adaptation of Micron X-15 spray head. Now the manufacturer has developed two versions, V3E and V3M, specifically designed for acridid control by incorporating significant improvements including direct drive atomiser, folding mast with locking extension arm, an increased capacity tank and a standard or electronic in-cab flow controller and atomiser speed. These two new models are equipped with X-9 DD spinning disc atomiser mounted in the mast so that, when it is in use, it protrudes beyond the back of the vehicle. The difference between the two versions is that the V3E is equipped with an electronic controller of the atomiser speed ant the flow rate.

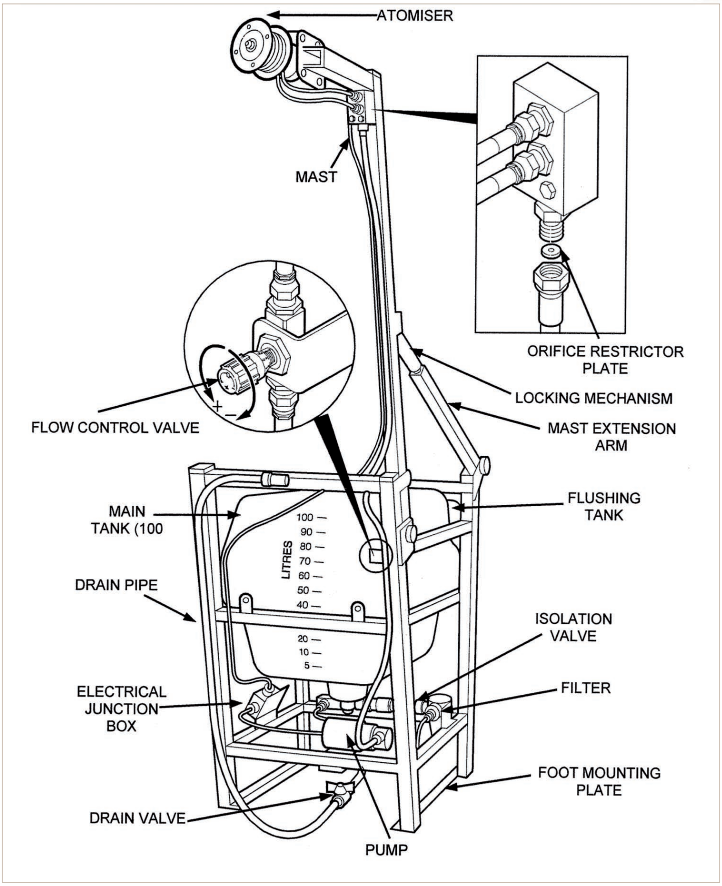
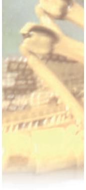


Figure 48. Description of the principal components of the Ulvamast (after Micron Sprayers).

Adjustment of droplet size

With the V3E model, it is possible to select the atomiser rotational speed from 3,700 to 7,800 rpm by means of the electronic control box. This flexibility is very important for keeping the droplet size within an acceptable range, especially when the viscosity is high or when performing barrier treatment for which high flow rates (around 1.6 l/min) are required.

With the V3M model an increase of the flow rate or in the viscosity results inevitably in an increase of droplet size because there is no way to increase the rotational speed of the atomiser. Nonetheless, even with an output as high as 1.5 l/min the speed is around 6,600 rpm and the VMD estimated at 75 microns which is very good for controlled drift spraying (CDS).



Specifications of VM sprayer types	
Weight	65 kg
Power	Voltage: 12 V DC Strength: 8 A maximum
Frame	30 and 40 mm box section mild steel Folding mast and support arm. Nylon coated
Tanks	Formulation tank: 100 l, 5 litres graduations Flushing tank: 10 litres Moulded metal insert, no straps UV stabilised high density polyethylene
Pump	Mechanically coupled proportionate gear pump
Hose material	Flexible stainless braided PTFE lined hose
Fittings	Plated steel brass fittings with union nut connection for maintenance
Electrical cable	Protected by black nylon conduit
Atomiser speed adjustment	Single speed of 7,000 rpm for V3M 3 speeds for V3E (4,500, 6,000 and 7,200 rpm)
Control box	V3M: standard on/of pump and atomiser control Fused with Led and light
	V3E: electronic control. Master on/off; 3 atomiser speed settings 10 flow control settings. LED lights-fused

Flow rate (ml/min)	High speed V3M and V3E		Medium speed V3E only		Low speed VE3 only	
	rpm	VMD	rpm	VMD	rpm	VMD
0	7,800	–	5,200	–	4,000	–
200	7,600	50	–	–	3,900	90
300	7,400	55	5,000	65	3,850	95
500	7,000	60	4,850	75	3,800	105
1,000	6,800	70	4,700	85	3,700	120
1,500	6,600	75	4,500	95	3,700	130

Table XXI. Droplet size against flow rate and rotational speed of V3E and V3M atomiser(after Micron Sprayers, 1999).

Restrictor number	Flow rate (ml/min)
24	108
30	149
39	294
49	461
59	581
68	709
80	957
98	1210

Table XXII. Flow rate with regards to the restrictor position, with V3M sprayer (after Micron Sprayers, 1999). Flow rate will vary with liquid viscosity.

Restrictor position	Flow rate (ml/min)
1	200
2	250
3	300
4	400
5	500
6	600
7	800
8	1,000
9	1,250
10	1,500

Table XXIII. Flow rate according to the flow control position, with V3E sprayer. The test was made with oil (after Micron Sprayers, 1999).

Flow rate calibration

With the V3E model, there is a need for frequent flow measurements. This is particularly interesting for stabilizing the flow rate when the viscosity varies with the temperature. Calibration is thus simpler: there are ten preset flow rates on the electronic controller and actual check.

Flow calibration of the V3M model is operated by the combination of an orifice restrictor plate and a progressive control valve. Each sprayer is provided with a set of various restrictor plates (tab. XXI). The flow is controlled via the orifice restrictor plate and adjustable needle valve. Referring to the table, the orifice restrictor plate can be selected according to the required flow rate. If the output obtained is not suitable, then a larger or smaller orifice plate can be used. The full calibration procedure of models of this kind is explained in the following chapter.

Maintenance

Regular maintenance is critical to keep the sprayer in proper working order. Therefore the following operations should be regularly undertaken:

- Remove pesticide deposits on external surfaces by wiping them down with a tissue soaked in kerosene, diesel oil or soapy water.
- Flush the sprayer through with kerosene or diesel oil, from the auxiliary flushing tank.

- Make sure that hose pipe connections are secured and leak free.
- Make sure that the atomiser spins freely and the disc is in good condition.
- Never run the pump without liquid.
- Occasionally check and clean the in-line filter.
- During transport between sites, the mast should always be secured in the folded position and the dust cover used to protect the atomiser.

Should any malfunction occur, it will be necessary to diagnose the problem:

- **Atomiser does not work:**

– check electrical connections and the fuses in the control box,
– check the battery condition,
– check if the atomiser spins freely.

- **Spray liquid is not emitted from the atomiser:**

– check that the two way valve is in a correct position,
– check if the pump works fine,
– check for plumbing leak and/or blockage,
– check that the in-line filter is not blocked.

- **No flow from the pump:**

– check if there is sufficient liquid in the tank,
– check that the in-line orifice restrictor is not blocked,
– check the electrical connections and fuses in the control box (V3M model only),
– check if the in-line filter is not blocked,
– check that the pump impeller is not obstructed (motor runs with no flow). This may require disassembly of the pump.

The exhaust nozzle sprayer

The exhaust nozzle sprayer (ENS) was originally designed for the control of the Desert locust hopper bands by the ultra low volume application of persistent insecticides. Exhaust gases from a vehicle engine are used to shear the spray liquid into 70-90 microns VMD droplets which are projected upwards and then drift downwind. Exhaust gases are directed through a flexible hose to the spray nozzle, the orifice of which is selected to suit the particular vehicle and engine.

A pressure gauge with 100 mm diameter, reading 0-1 bar is fitted to a protective cowl and connected to the unit by means of a length of hose. The gauge and the cowl are usually fitted to the vehi-

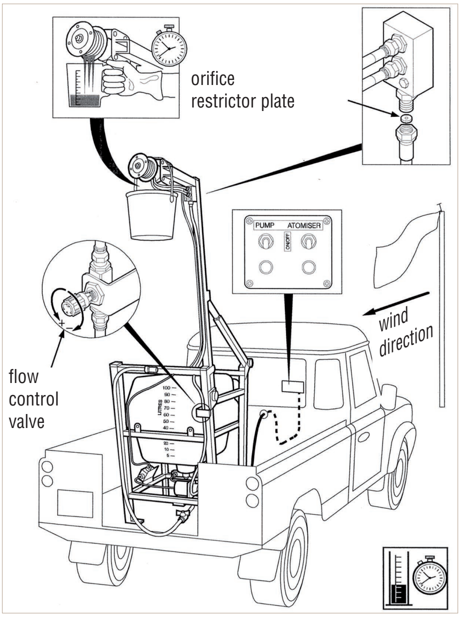


Figure 49. Setting flow rate of V3M sprayer (after Micron Sprayers).

cle so that the operator can check the pressure all the time. A safety valve prevents excessive back pressure which may damage the engine. Pressure of the exhaust gases is also used to force the spray liquid through the nozzle.

The sprayer is operated so that a wind across the line of travel takes the 70-90 microns droplets downwind away from the vehicle. Swath widths vary with wind speed. For example, with 10-15 km/h winds, at 1.2 l/min output and vehicle speed of 10 km/h, the application rate is 0.3 l/ha over 300 m swath which is suitable for the low acting insecticides for barrier treatments.

The sprayer ca be fitted to most types of four wheel drive vehicles used by locust control operators. Whatever vehicle used, it should have a double-ratio gear box and an enclosed cab for the driver to be protected from the insecticide spray.

The ENS is the cheapest and simplest vehicle-mounted sprayer. However calibrations are very difficult to achieve and stabilize. Besides, recent machines are equipped with nozzles that produces a poorer droplet spectrum than the ones on the old machines. These flaws and the difficulty of spare part supply led locust operators to prefer the vehicle-mounted electrical sprayers.

Aerial equipment

Historical background

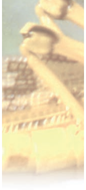
Right from the beginning, aviation pioneers tried to use aircraft in agriculture. Considered as the father of agricultural aviation, Alfred Zimmerman (1876-1964) was granted a patent for the use of aircraft in the control of insect pests in forestry management.

The real start of agricultural aviation was during the 1930's when the aircrafts used for aerial application work came from the military surplus of the First World War. It was not until the 1950's that commercial aircrafts specially designed for aerial applications came into being. Through advances in chemical technology, a more economic use of aircraft was made possible, because small quantities of chemicals were successfully used (Quantick, 1985). Now agricultural aviation is practised on all continents, numbering more than 40,000 aircrafts all over the world.

In locust control, the first aerial low volume (LV) trials were realized with aircrafts equipped with boom-and-hydraulic nozzle during the late 1940's. But the use of aircraft in locust control was boosted with the introduction of the first Micronair by the company Britten Norman. It was then possible to produce droplets fine enough to allow drift spraying.

During the 1986-1989 plague, aerial application covered approximately 14 million hectares in Africa and the Near East and 4 million hectares during 1993 in Asia and Africa. The importance of aerial applications in this domain depends upon the acridid situation which is a consequence of outbreaks and recession periods.

From a strictly financial point of view, aerial applications are only justified when vast areas are involved. Efficiency in these conditions is from five to ten times higher than with ground applications. But in locust control aerial interventions are often required even when areas really infested are relatively small, especially



when early action is more important than financial considerations. However, it should be noted that the availability of logistic support on the ground is a key factor in the cost of the operation.

Criteria of acridid control aircrafts

Aircrafts used in acridid control are usually confronted with very challenging atmospheric conditions. The engine, the aircraft structure and the spraying system must be robust and simple, so that some repairs could be done easily by the pilot himself. Airplanes should have a good manoeuvrability, since they must fly at low level with relatively low speed. Therefore it is essential that they have sufficient climbing capabilities. The lateral stability at the stall should be such that if the aeroplanes is in a flat skidding turn and the control stick is eased full back, the aeroplanes will continue to turn under control and will not suddenly increase its bank and start into a spin or flick the other way and spin as with some aeroplanes in use in application work (Quantick, 1985).

Atmospheric conditions such as high air temperature may affect engine efficiency consequently climbing performance of the aircraft. It must be noted that nominal specifications (tab. XXIV) are given for standard atmospheric condition i.e. a temperature of 15° C and a pressure of 1,013 hpa at sea level. A rise of temperature and altitude of operating site may result in a decrease of aircraft capabilities. It is therefore wise to accept the pilot's decision when he refuses to board some more passengers for a survey flight even though there are still some unoccupied seats. Fuel and spray equipment must be considered as being a part of the cargo.

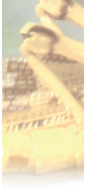
All elements should contribute to ensure the security and saving of running costs. The main desirable characteristics of acridid control aircrafts are:

- To be able of to lad a cargo up to 35 to 40 % of their gross weight.
- To be capable of getting over a 15 m high obstacle after taking off from a bare earth strip of 400 m in standard air at sea level.
- To have a high climbing speed.
- To have a low stall speed (65-100 km/h).
- To be able of flying at low altitude with a 130-200 km/h operating speed.
- To be able to turn sharply at low altitude.
- To own a cockpit which allow a good view forward and own for clearance of any obstacle such as fences, trees and wires. A good view ahead over the nose is necessary for taxiing in small unprepared an temporary air strip.
- The design of the forward fuselage and the cabin structure should resist nominal crash loads as well as flight and landing loads. Aircraft structures should absorb energy by progressive by progressive collapse. Shoulder harness, safety belts, seats and anchorages should be comfortable but also of enough strength to resist failure up to the point of cabin collapse. The cabin should be pressurised so as to avoid poisoning the pilot by pesticides.
- The hopper is located ahead of the cabin, so that it remains within the limits of the centre of gravity during take off. The hopper should have a large door located to allow easy and quick loading either by hand or by machine. The hopper should by fitted with a device for jettisoning the load in case of emergency.

Airplane	HP	Empty weight (kg)	Take off weight (kg)	Take off length (m)	Cruise speed (km/h)	Stall speed (km/h)	Climbing speed (km/h)
Anahuac (Mexico)							
El Tauro 300	300	1,606	800	–	137	81	152
Antonov (Poland)							
AN2M	1,000	5,500	1,960	200	200	75	132
Britten Norman (UK)							
Islander	600	–	1,000	250	220	70	–
Cessna (USA)							
Ag Wagon	285	1,497	757	257	183	92	210
Ag Truck	285	1,497	1,056	207	166	92	210
Ag Carryall	300	1,514	569	290	180	90	257
De Havilland (Canada)							
Beaver Turbo DHC2 MKIII	578	2,313	910	152	225	97	361
Grumman (USA)							
Ag Cat	450	2,041	980	228	161	107	329
Super Ag Cat	600	2,041	1,133	120	177	–	–
Pilatus (Switzerland)							
Turbo PL6 B1-H2	550	2,200	1,176	198	202	112	460
Piper Aircraft (USA)							
PA 18A	150	949	370	92	145	69	232
PA 25	235	735	600	400	160	90	350
Pawnee brave PA 36	300	1,085	860	488	180	106	488
Rockwell Int. (USA)							
Turbo Trush SR2R	750	1,633	2,086	183	153	106	400
Air Tractor AT302T	600	1,474	1,457	238	217	82	606

Table XXIV. Specifications of some airplanes used in pest control (after Castel, 1982).

- Fuel tanks should be located in or on, the wings far away from the cabin and the engine.
- It is extremely important that the aircraft be inspected and maintained easily and repaired quickly in order to keep it on operation without loss of time, especially during intensive locust control campaigns. All control linkages and critical parts should be visible and easily inspected. Materials and paints should resist corrosion of formulations.
- The cooling system should be designed large enough to avoid excessive rise in temperature.
- In acridid control areas, air often carries a lot of dust. Aircraft should therefore be equipped with an efficient anti-dust system. The engine should be well protected by judicious location of the carburettor air inlet, the use of ample air filters and, under adverse conditions, by the use of fuel-flow filters.



Aircrafts used in acridid control

Aircrafts which can be used in acridid control depend on tactic and the importance of target zones. The use of helicopters is increasing thanks to a relative decrease of their cost-in-use and the possibility of using them in areas without airstrips. The attempts to introduce ultra light aeroplanes, in the Sahelian area, were not satisfactory so far, because they are too fragile against sudden and frequent air turbulences.

Heavy cargo aeroplanes

This type of aeroplane can carry a cargo of several tons, over a 500 km distance. Their size does not allow them to land in short and unprepared airstrips, frequently used in acridid control. Their long range compensates for this disadvantage but their cost-in-use is very high. Actually, they are useful only in a few cases, when vast areas over hundreds of thousand hectares lying together are to be treated rapidly.

Medium sized and light aeroplanes

Aeroplanes of this type are frequently utilized since they are reliable from a security point of view and the improvement of their productivity. Aeroplanes designed specifically for aerial applications belong to this category. They are rustic and capable of taking off and landing on short and rough runways; their taking off distance is short (200-400 m). Many brands and models were recently used in acridid control (tab. XXIV). The most commonly used among light aeroplanes are Piper PA 25 Pawnee, Cessna Ag Truck and Ag Wagon. Among medium-sized aeroplanes recently used in acridid control are Britten Norman Islander, Antonov AN2, Turbo Trush, Grumman Air Tractor.

Helicopters

Helicopters have a reputation of being expensive to use. However, their recent use in locust control showed that this assessment should be mitigated in favour of helicopters for several reasons. Modern equipment with various specifications make it possible to select the most efficient solution and therefore to decrease the costs. Besides, helicopter are ideal to intervene on locust infestations located in an area hard to get by ground. The use of helicopters is critical when it is required to combine survey and treatment on a given area. It is actually possible to land on a precise spot and scout around. It is also possible to perform preventive surveys on vast areas within the range of the helicopter (tab. XXV), mark out areas to be treated by aeroplanes and perform after treatment checks.

For acridid control in the Sahelian countries, helicopters are often justified because they can be used either directly for treatment or for supporting large scale interventions by aeroplanes. Their potentialities are fully utilised when their use is planned long in advance and fuels and lubricants made available on key spots before the beginning of the monsoon.

Advantages of helicopters are fully expressed by the possibility of making direct contacts with farmers and shepherds who may help to locate swarms, egg fields, hopper bands or grasshopper infestations.

Beside their professional skill, crews should have good adaptability to Saharan-Sahelian conditions and human qualities for making useful contact with local populations.

Helicopter	HP	Persons aboard	Empty weight (kg)	Take off weight (kg)	Cruise speed (km/h)	Range (km)
Alouette III	870 550	1 + 6	1230	2200	195	500
Alouette II SA 313	–	1 + 4	1020	1600	175	320
Alouette II SA 318	360	1 + 4	1050	1650	175	580
Lama SA 315	870 550	1 + 4	1080	1950	180	500
Bell 206 Jet Ranger	420 370	1 + 4	720	1450	215	752
Bell 47 G2	260	1 + 2	740	1110	120	310
Bell 47 G4	320	1 + 2	840	1335	130	450
Ecureuil	650	1 + 5	1050	1950	220	620
Ecureuil 350 B2	742	1 + 5	1134	2500	236	670
Hughes 500	450	1 + 5	700	1360	220	450

Table XXV. Specifications of some helicopters used in pest control (after Castel, 1982 and Chaussepied, p.c. 1990).

Aerial spraying equipment

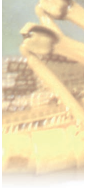
In most cases of acridid control, applications involve the use of ULV formulations. Volume of application generally varies from 0.5 to 3 l per ha, although 1 l/ha is the most frequently used volume. The equipment described below is basically designed for ULV applications.

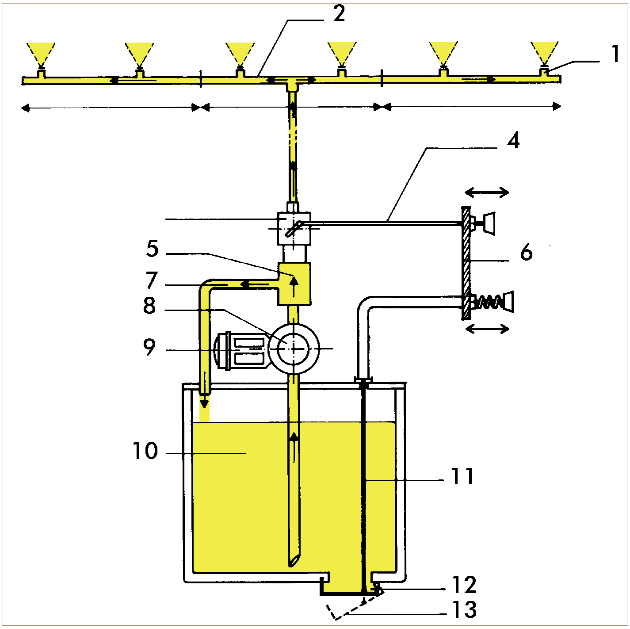
Spray gear

Spray gear (fig. 50) is the name given to the equipment through which the liquid flows from its loading to the spray head. The main components are:

Chemical tank or hopper

The hopper capacity varies between 300 and 700 l for light size and 800 to 2,000 l medium-sized aircrafts. They are, most often, constructed from fibreglass so that they may be repaired in the spot. They have a translucid zone visible out of the fuselage. A translucent window before the pilot allows him to follow up the level of liquid in the hopper.





1: spray head
2: boom (3 sections in helicopter)
3: three way valve
4: spray command transmission
5: flow regulator
6: command panel (in the cockpit)
7: way back to the tank
8: pump
9: motor
10: tank
11: dump valve command
12: tank bottom
13: open position of dump valve

Figure 50. Diagram of a typical aircraft spray system.

For security reasons, the hopper is situated inside the fuselage, between the cockpit and the engine. Thus, albeit aircraft evolution in the air the cargo weight remains within the limits of the centre of gravity.

The jettisoning device should be designed so that the load can be released within 5 seconds. Belly tank stowed to the underside of the fuselage or pods mounted on standard underwing pylons could be jettisoned, with their load, in an emergency.

Some helicopters are equipped with twin tanks mounted on each side (fig. 51). The tanks communicate with each other so as to maintain the balance between lateral weights with regards to centre of gravity.

Filters

It is critical that the liquid be filtered before it flows to the spraying system because solid particles may agglutinate and plug check valves, nozzle filters or the flow regulator. If the filtration is deficient, the spray will be highly affected. This is the reason why several filters are placed along the circuit of liquid.

A wide basket filter is located at the filling point. The liquid flows through a second filter just before or, according to various systems, after the pump. A final

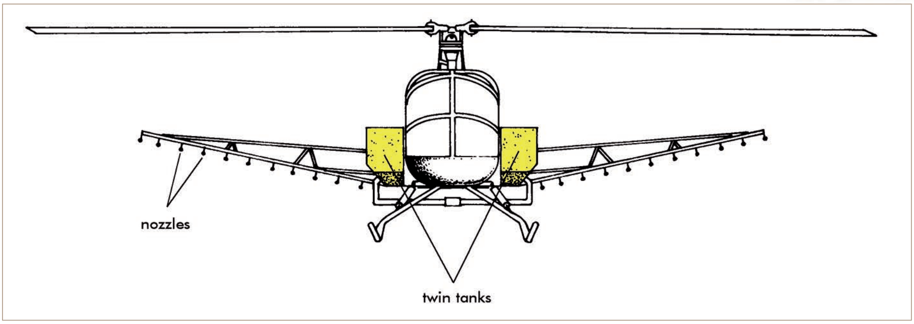


Figure 51. Helicopter with twin tanks equipped with a hydraulic nozzle spray boom.

filter is sometimes placed just before spray head, as is the case with hydraulic nozzles.

It is highly recommended to regularly clean the filters so as to avoid breakdowns which may have serious consequences. Therefore they should be easy to reach and clean.

Pumps

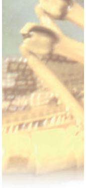
Every spray system is equipped with a pump which supplies the liquid, under a given pressure, to the spray boom and atomising devices. The working pressure usually varies from 1.5 to 5.6 bars. The efficiency is 25 % for centrifugal pumps and 20 % for gear pumps. Pumps should be powerful enough to ensure the maximum output required and provides agitation of liquid in the tank by continuous re-circulation.
There are several types of pumps, each having advantages and disadvantages:

A. Centrifugal pumps (fig. 52 and 53)
They are suitable for large volume (up to 550 l/min) at low pressure. Viscous liquid can be pumped. The volume of liquid emitted decreases rapidly when the pressure exceeds 2.5-3.0 bars. If the outlet is closed when the pump is running, the pressure rises slightly without causing damage.

These self-priming pumps have to be located at the lowest place of the circuit so as to be primed even when there is a little amount of liquid in the tank. Centrifugal pumps usually run at high rotational speed (4,000 rpm).

B. Gear pumps
They consist of two meshed gears, where one of them is connected to the drive source (fig. 54). The liquid is drawn between the gear teeth which rotate in opposite directions. The teeth are coated against corrosion with a protective layer.

Gear pumps are fragile, thus they are usually equipped with a relief valve to prevent damage which may be caused by excessive rise in pressure. Output might be adjusted from 5 to 200 l/min with a pressure of 7 bars.



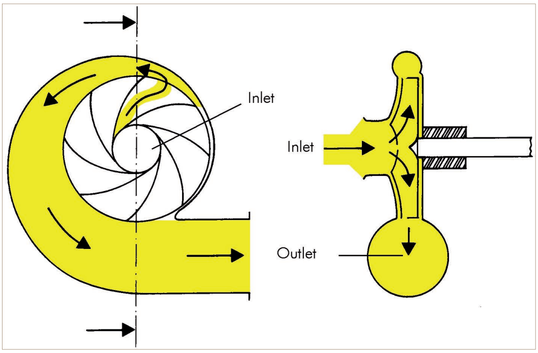


Figure 52. Centrifugal pump functioning (after Musillami, 1982).

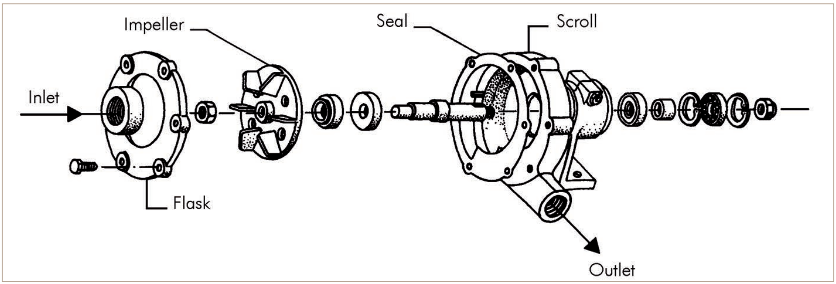


Figure 53. Layout of a centrifugal pump (after Berthoud in Musillami, 1982).

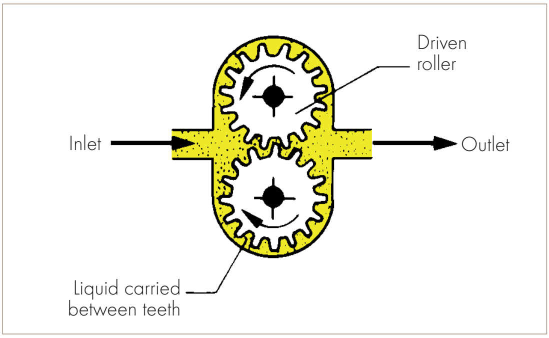


Figure 54. Cross-section of a gear pump (after Matthews, 1979).

C. Roller pumps

Inside the eccentric case of the pump, a rotor with five to eight slots, rotates (fig. 55). In each slot a roller rotates while moving in and out to catch and eject the liquid. The rollers are usually protected against corrosion by a layer of Teflon.

Roller pumps are normally designed to rotate at 1,000 rpm and an output from 20 to 140 l/min under a pressure of 20 bars. The flow varies with the rotational speed.

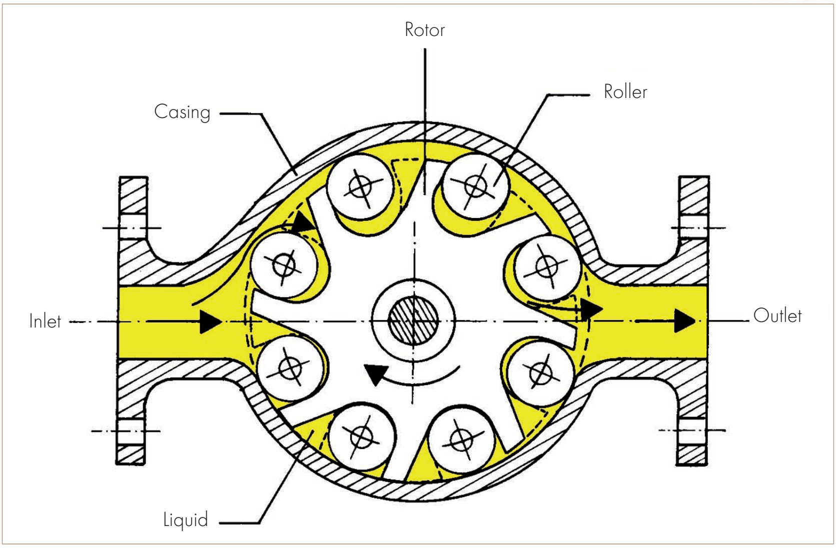


Figure 55. Cross-section of a roller pump (after Matthews, 1979).

Pump drive

The driving system of pumps in aircraft partially depends on the type of aircraft.

A. Air driven pump

This system (fig. 56) is simple and relatively cheap. The energy does not depend directly upon the aircraft engine. In the other hand, it is sensitive to airspeed and the flow rate calibration cannot be performed on the ground. Yet, a propeller with adjustable plastic blades is preferable (Castel, 1982). It is important to provide a brake to stop pumping during manoeuvring flights.

Advantages of a pump with adjustable propeller blades (Castel, 1982):

- It is lighter than fixed metallic blades.
- It is possible to adjust the output so as to avoid an important back flow to the tank (small output for ULV). This calibration is made by setting the angle of the blades. Wider the angle, lower the rotational speed of the pump.
- It is possible to use 3 to 6 blades according to the power required.
- It is not required to dismantle the propeller before convey flights; to this end, blades should be feathered.

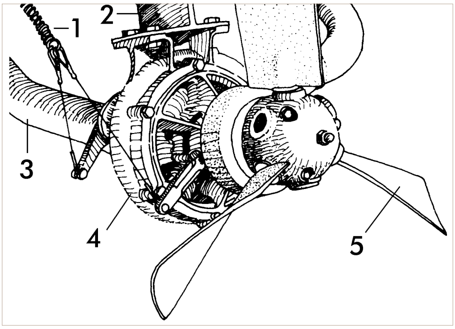
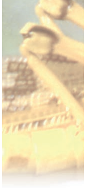


Figure 56. Air-driven pump (after Shell, 1983).
It is fixed under the fuselage, behind the aircraft propeller.
1: brake cable; 2: outlet; 3: inlet;
4: pump casing; 5: adjustable blades.



B. Hydraulically-driven pump

This type of energy transfer is rather common; it is steady and easy to repair. Its main disadvantage is being heavy. It is mainly used to equip helicopters.

C. Mechanically-driven pump

This pump is in direct drive by the aircraft engine. It is usually installed in helicopters but it is difficult to set them in older aircrafts. However they are light, simple and economic. These advantages argues for the extension of their use in new aircrafts.

D. Electrically-driven pump

The efficiency of electrically-driven pumps is good when the power is below 1.5 HP. Above this, powering the electrical system on board becomes expensive. Electrical sources of energy are used in helicopters for ULV and VLV spraying system. New electrical equipment is well-designed so that they are not affected by excessive high temperatures.

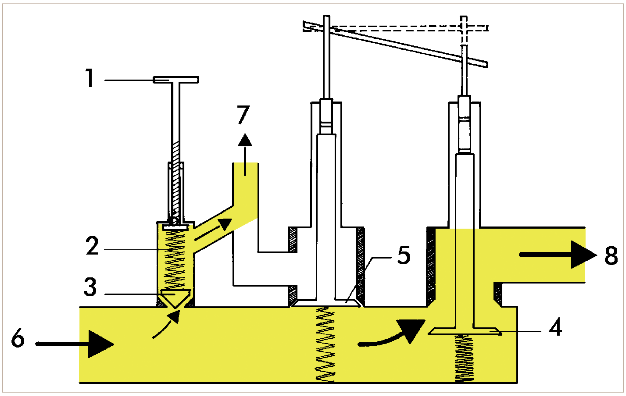
Pressure and flow regulators

Basically they are designed on the principle of a valve with a progressive closing of the back flow to the tank. Closing the valve induces a pressure rise in the system. When a large amount of liquid returns to the tank, the pressure decreases in the circuit which reduces the flow of liquid to the spray boom. By adjusting the flow of liquid returning to the tank, the spray system is protected against excessive pressure which may be detrimental. When the spray is stopped, a bypass allows the liquid to return to the tank.

Two types of regulators are mounted on aircrafts:

A. Sorensen type valve (fig. 57)

The variation of pressure is obtained by tightening a spring (2) of a teflon needle (3) which controls the return of liquid to the tank. The command button (1) of the needle is located in the cabin within the reach of the pilot's hand. The start and the stop of the spray is operated by a simultaneous action of the outlet (4) and return valves (5).



1: command button; 2: spring; 3: teflon needle; 4: outlet valve;
5: return valve; 6: inlet; 7: back to the tank; 8: outlet.

Figure 57. Layout of Sorensen type valve (after Sorensen).

B. Three way valve

It is basically a three way sphere. It swivels round so that it lets a flow of liquid, more or less important, towards the spray boom. The bearing and the sphere are Teflon-coated to protect against corrosion and waterproofness. In a bypass circuit, a screw modulates the amount of liquid which returns to the tank. This bypass opens onto a Venturi where the liquid speeds up (fig. 58 and 59). When the pilot closes the valve to stop the spray, a pressure drop occurs in the boom and immediately stops the flow of liquid and hence emission of droplets. A three way valve ensures a good and progressive flow rate calibration from "0" to the maximum possibilities of the pump and the spray system.

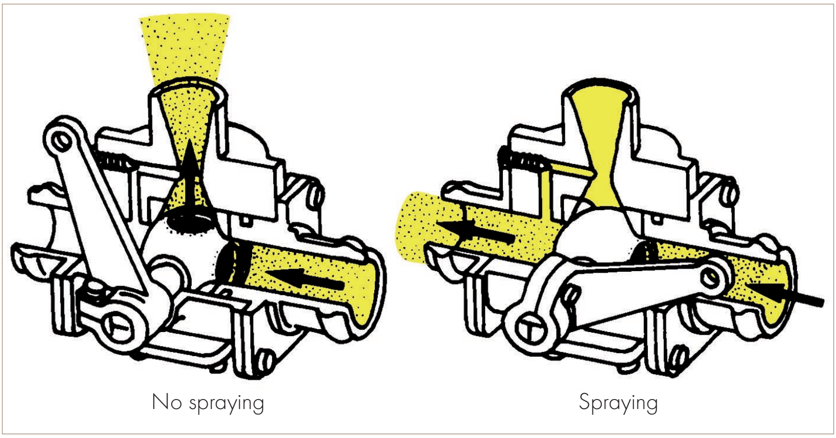


Figure 58. Three-way valve (after Shell, 1983).

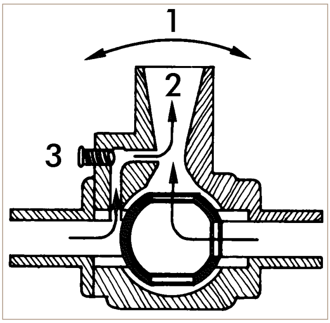
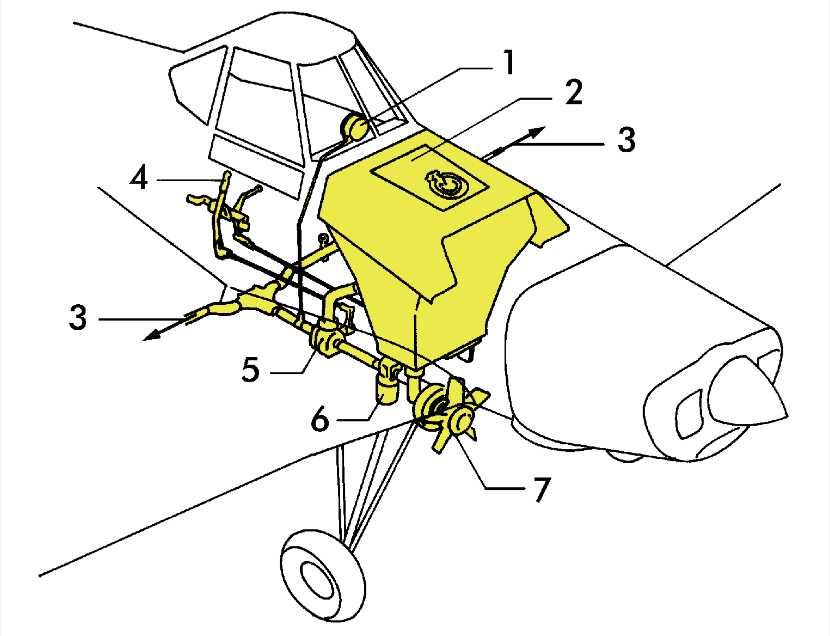


Figure 59. Cross-section of the three-way valve (after Shell, 1983).

Manometer (pressure gauge)

The pressure at which the spray is emitted is an important factor in the spray quality. Pressure reflects the state of liquid flow inside the spray system. Hence, pressure variation should be monitored in the cabin so that the pilot may constantly see what is going on in the circuit. Therefore the manometer should be easily visible to the pilot.

Before taking off, the pilot should be sure that the manometer is working properly. The needle of the manometer should return to "0" when the system is switched off. If not, it means that the flow regulator does not function properly. The relative position of the manometer in the circuit is almost always the same in all aerial spray systems (fig. 60).



1: manometer; 2: filling cap; 3: outlet; 4: spray command; 5: spray valve; 6: filter; 7: pump.

Figure 60. Position of the components of an airplane spraying system (after Shell, 1983).

Spray boom

In fixed wing aircrafts the spray boom is generally as long as the wingspan. It is generally fixed at the back of the wing but actually this depends upon the wing position in relation to the fuselage (above or below the wings). The booms is often a hollow tube or streamline cross-section, made of stainless steel, brass or aluminium alloy (fig. 61).

On helicopters, the boom is smaller than the rotor, with a maximum of 15 m. It is composed of three sections where the central third is placed at the back under the turbine. The boom should be able to be dismantled easily and rapidly or folded up, so as to enhance the efficiency of the helicopter (fig. 62 and 63).

Atomising devices

Although there are still some boom-and-nozzle gears, the primary airborne equipment used in acridid utilize rotating atomisers. Hydraulic energy nozzles are less frequently used in acridid control because droplets are not fine enough to suit ULV. However for LV and VLV spray technique, the boom-and-nozzle gear is acceptable.

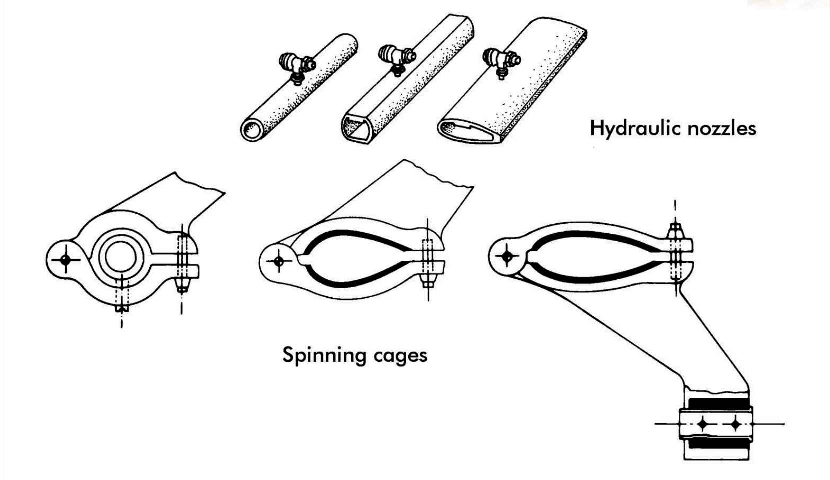


Figure 61. Fitting of different nozzles on spray booms (after Shell, 1983 and Micronair, 1987).

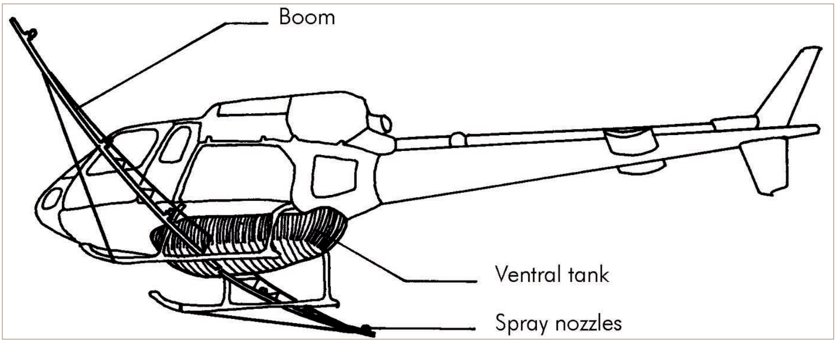


Figure 62. Helicopter with treating spray boom (after Aerospatiale).

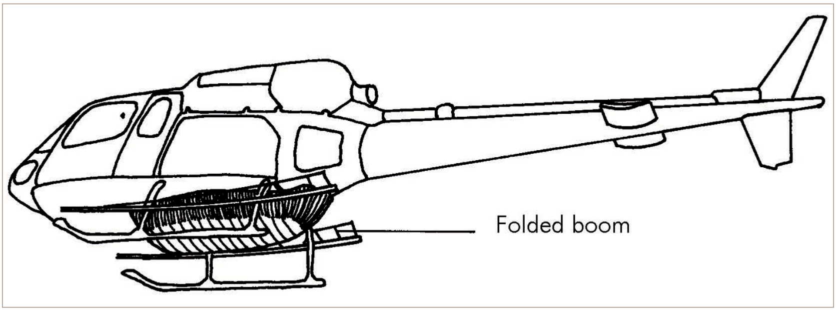
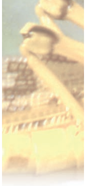


Figure 63. Helicopter with folded spray boom for ferry flying or survey (after Aerospatiale).



Hydraulic nozzles

The most commonly used are fan nozzles and cone nozzles. Spray boom comprises 20 to 50 nozzles, 16.5 to 33 cm from each other so as to ensure an uniform spray even when some of them are blocked up (fig. 51).

For LV and VLV applications, cone nozzles are commonly used (fig. 9). Flat nozzles, more suitable for applications of herbicides, are not used in acridid control. Each nozzle is equipped with an anti-drip diaphragm system, as it is important that no chemical leaks from the system when the pressure drops (fig. 64). When the pump is shut or the valve is closed, the pressure drops inside the boom. Although the diaphragm is coated with a thin Teflon layer, frequent checks are required to ensure its correct functioning.

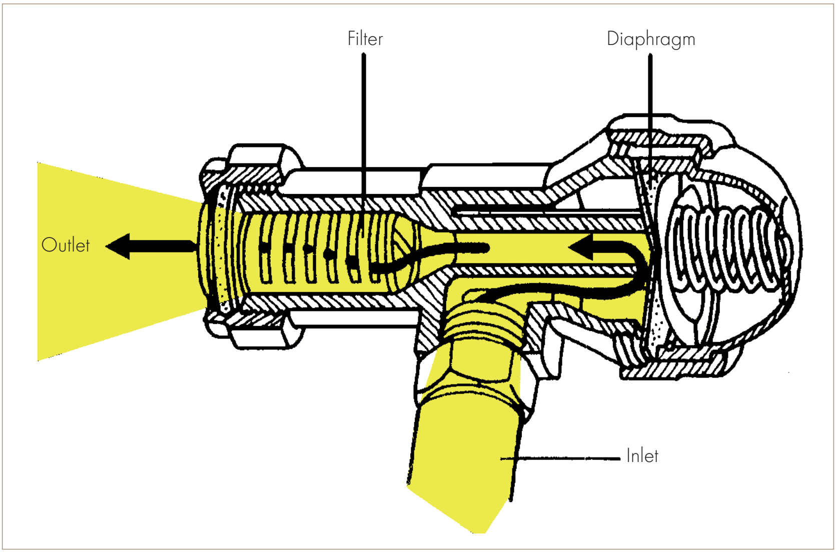


Figure 64. Cutaway of check valve (after Shell, 1983).

The output depends upon the working pressure, the number of the nozzles and the diameter of the orifice. To alter the output, it is required to modify the number of nozzles in combination with the orifice diameter. However it should be noted that the output of a nozzle is proportional to the square root of the pressure; so doubling the working pressure only increases output by 40%. Therefore basic adjustment should be achieved by altering the number and/or the size of the nozzles (Quantick, 1985).

Droplet size varies with the working pressure, the type of nozzle and their orifice and the nozzle orientation. Thus when nozzles are pointed backwards, the spray and slipstream are travelling at similar velocities and there will be little shear at the air/liquid interface causing production of large drops. If nozzles are pointed forward into the slipstream, the difference in relative velocities is maximized and the increased shear produces fine droplets (fig. 10). Despite this possible adjustment, droplet spectrum produced with boom-and-hydraulic-nozzles is too coarse to meet the requirement of optimal ULV technique.

Where aircrafts are frequently used in application of herbicides, for the purpose of reducing the size and weight of spray systems, it is possible to fix spray boom hydraulic nozzles and atomiser as well. Thus it is possible to use alternatively the former to spray VLV and LV aqueous formulations and the latter to spray ULV oily formulations.

Rotary atomisers

These droplet generators, furthered the development of aerial ULV applications. Droplet generation is realised by high rotational speed of a spray head. Droplet spectrum is narrow and fine, suitable for good quality ULV applications allowing large swath width. Adjustment of droplet size is realised by monitoring the rotational speed of the atomiser. At present, most of aircrafts used in acridid control are equipped with rotary atomisers.

Atomisers may be electrically-driven (Airbi, Beecomist or Micronair) or by a hydraulic system (Micronair) or propeller-driven Micronair and Curtis ASC-Line). Airplanes are usually equipped with propeller-driven system systems while helicopters are equipped with hydraulic or electric systems.

Many models of several brands are proposed. The most common are Micronair rotating cages, Curtis Agri-Line ASC system and Beecomist spray head.

A. Micronair rotating cages

Micronair rotating cages are most commonly used in acridid control. The atomiser consists of a cylindrical gauze rotating around a fixed spindle which is attached to a mounting brackets on the aircrafts.

Several variants are available. They can meet requirements of different aerial equipment.

AU4000

AU4000 rotating cage (fig. 16) is robust and not vulnerable to loss of balance. This model has a good distribution over the gauze and capable of releasing sprays with fine droplets and narrow spectrum. The output varies from 0.3 to about 23 l/min. So, it is suitable in acridid control.

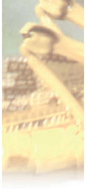
AU5000

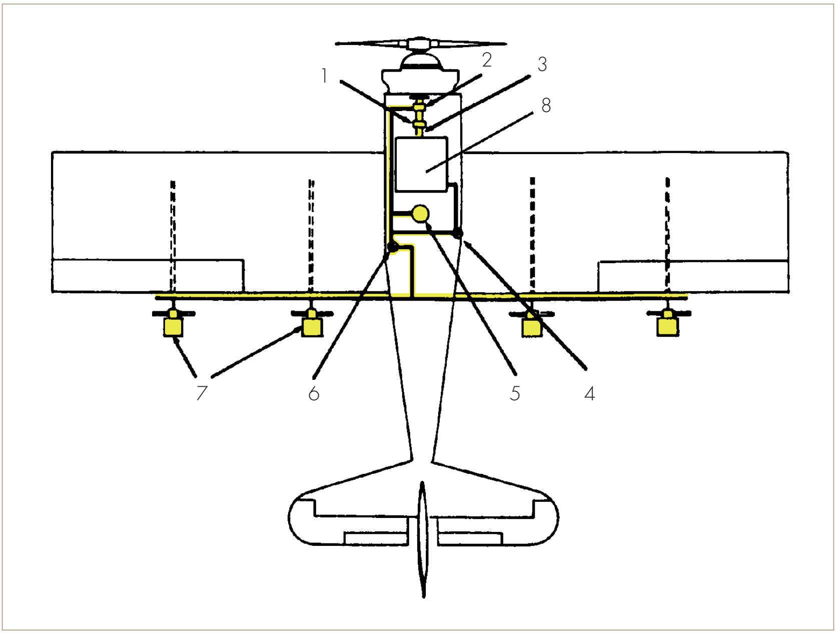
This mini-cage was formerly developed for ground airblast sprayers. It is now extensively used both in aircrafts and helicopters. It is similar to AU4000 but lighter. Thus, it is possible to fix 10 units instead of standard boom-and-hydraulic-nozzle. Each AU5000 atomiser can handle a flow up to 23 litres/minute which enables the same installation to be used for a range of output rates from ULV to conventional applications at 20-50 litres/hectare.

AU7000

It was developed primarily for ground airblast sprayers. It is similar to AU5000 but smaller. It is driven by four adjustable fan blades to provide additional power even at slower air speeds. It is well suited for microlight aircrafts, where weight is of great importance. The output can be adjusted from 0.2 to 6 litres/minute under a working pressure of 10 to 20 psi.

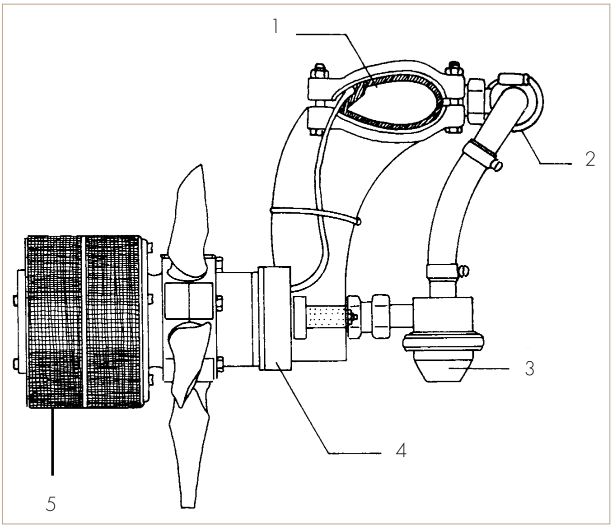
Frequently, four atomisers are fitted to a light aircraft such as a Piper Pawnee PA 25 (fig. 65). With new models, more compact and lighter, it is possible to adapt the spray system according to the aircraft type and the tactic needs. Thus it may be possible to shorten the distance between spray heads for fixing a greater number on the same spray boom.





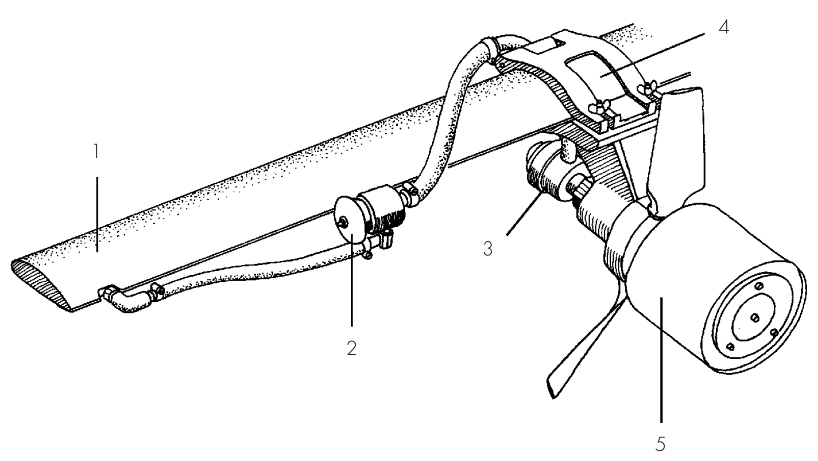
1: filter; 2: pump; 3: inlet; 4: flow regulator; 5: manometer; 6: spray valve; 7: spray head; 8: tank.
Figure 65. Layout of Micronair spray heads (after Micronair, 1986).

The Micronair system is composed of a cage, fan blades, a check valve, a flow metre and a flow monitoring system (fig. 66 and 67).



1: boom cross-section;
2: VRU; 3: check valve;
4: brake;
5: spinning cage.

Figure 66. Fitting of a Micronair spray head (after Micronair, 1986).



1: boom; 2: VRU; 3: check valve; 4: fixing elements; 5: spinning cage.

Figure 67. Viewpoint of a Micronair spray head (after Micronair, 1986).

The cage

The cage consists of a cylindrical gauze rotating around a fixed spindle which is attached to a mounting bracket on the aircraft. Power is supplied from the air flow through five balanced delrin blades clamped in a hub, which also carries the gauze and the bearing assembly. The pitch of the blades is adjustable and this is used as the means of controlling rotational speed of the cage which varies from 2,000 to 14,000 rpm. The gauze is constructed of anti-corrosive alloy soldered to alloy diaphragm plate.

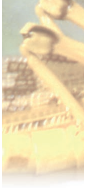
In case of damage or any conditions which may cause it to run out of balance, it must never be repaired in the field as it must be dynamically balanced after repair. Therefore it is preferably to replace the damaged cage by a new one and send it to the manufacturer for repair.

Chemical is introduced by the hollow spindle through a rotating deflector that distributes the liquid along the diffuser tube, which also rotates. An initial break up of the liquid is achieved here before it reaches the gauze. Atomisation is finally completed as the liquid is thrown clear of the gauze. The speed of rotation determines the droplet size.

Electric brake

An hydraulically or electrically-operated brake is fitted to the mounting bracket so as to stop the atomiser in the event of an emergency or during the ferry flying. The brake consists of a solenoid and friction lining mounted in the atomiser attachment block and a pole plate joined to the front plate of the hub assembly by means of a leaf spring. When the solenoid is energized, the pole plate is attracted to the face carrying the friction lining and the resulting torque stops the atomiser.

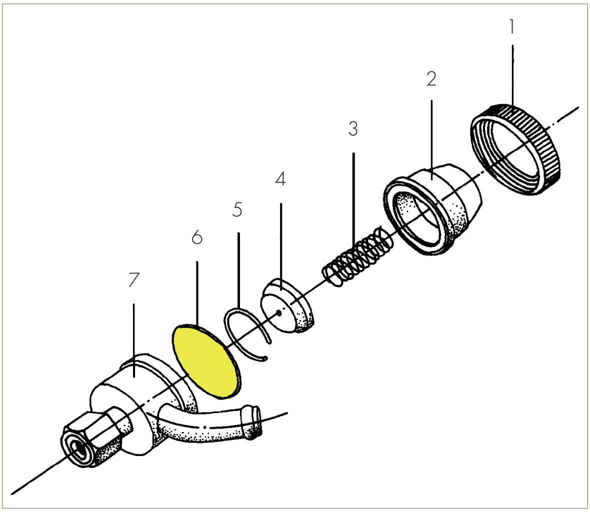
The electric brake is self adjusting and does not require any regular maintenance in service. Slight wear of the pole and the plate and solenoid assembly is normal, these parts must, however, be replaced if the wear becomes excessive and the efficiency of the brake is reduced.



Except in emergency (a broken fan blade), the brake should never be operated when atomisers are on rotation, because there is a high risk of damaging brake discs. It is preferably to brake them on the ground and release them before starting to spray. At the end of spraying they should be left rotating until complete stop of the aircraft.

Diaphragm check valve

The diaphragm (fig. 68) is designed to eliminate dribble from the atomiser after the spray is shut off. The unit is not a substitute replacement for the secondary shut off valve on the spindle inside the atomiser and is intended to hold back any static pressure in the spray system which could lead to leakage. The check valve is constructed from chemical resistant materials; the diaphragm being viton reinforced operating on stainless steel seat to ensure resistance to corrosive chemicals.



1: screw; 2: cap;
3: spring; 4: plunger;
5: spring clip;
6: diaphragm (viton);
7: body assembly.

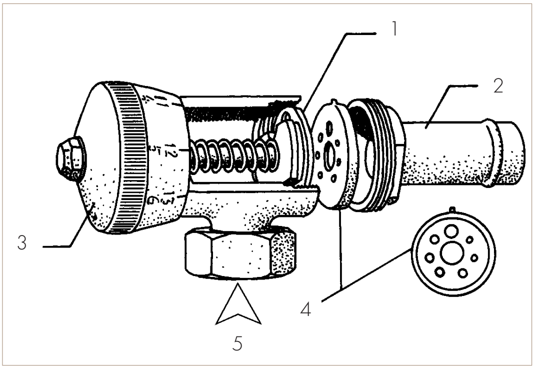
Figure 68. Diagram of a check valve (after Micronair, 1987).

Normally, the diaphragm check valve requires very little maintenance. However, it should be checked periodically, since chemical formulations are frequently changing and it is possible that the viton diaphragm may be attacked by unusual chemicals. If this happens replace with the correct spare part or advise the manufacturer.

Variable restrictor unit (VRU)

The variable restrictor unit (fig. 69) controls the flow of chemical to each atomiser (fig. 66 and 67) by means of an orifice plate with a number of holes of different drilled around its periphery. The orifice plate lies against a selector plate which has a single hole and attached by a shaft to a calibrated thimble at the end of the unit. The hole in the selector plate can be set to align with any one of the holes in the orifice plate, thus controlling the chemical flow according to the hole size. The thimble is made to "click" into the appropriate position by means of a spring in the VRU body which engages in groves inside the thimble. This ensure that the hole in the orifice plate is aligned with the hole on the selector plate. The posi-

tive location of the thimble eliminates any possibility of the selected orifice being altered unintentionally. A full position is also provided.



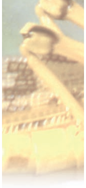
1: mobile orifice plate; 2: outlet; 3: selecting button; 4: fixed plate; 5: inlet.

Figure 69. Diagram of VRU (after Shell, 1983).

The knob of the VRU is marked with odd numbers 1-13 and even numbers 2-14. These numbers (tab. XXVI and fig. 70) correspond to the holes sizes in the "O" (odd) and "E" (even). The orifice diameters varies from 0.77 to 6.35 mm. Thus, for AU4000 atomisers, the flow rate varies from 0.34 to 21 l/min. A number of alternative plates can, however, be supplied on request to suit special needs (tab. XXVII).

Plate	Orifice		AU4000			AU5000		
	no	ø (mm)	30 psi	40 psi	50 psi	20 psi	30 psi	40 psi
"O" plate odd numbers	1	0.77	0.34	0.60	0.71	0.29	0.56	0.68
	3	1.18	1.25	1.55	1.82	0.77	0.95	1.18
	5	1.60	2.36	2.80	3.30	1.88	2.55	3.10
	7	2.40	3.70	4.20	4.80	2.56	3.88	4.77
	9	3.00	5.20	6.20	7.30	3.90	5.50	6.86
	11	3.97	8.00	9.60	11.00	6.46	8.25	10.45
	13	5.56	16.20	19.40	21.50	8.70	11.16	14.80
"E" plate even numbers	2	0.89	0.60	0.70	0.90	0.45	0.59	0.80
	4	1.40	1.25	2.00	2.23	1.25	1.90	2.31
	6	1.85	2.46	3.24	3.50	2.23	3.68	4.56
	8	2.65	3.80	4.80	5.54	3.11	4.03	4.97
	10	3.30	5.70	7.00	8.30	4.17	5.76	6.92
	12	4.76	10.20	12.20	14.50	7.53	9.26	11.86
	14	6.35	16.60	20.80	23.80	9.40	14.97	19.12
These figures are based on tests with water. Actual flow rates will vary according to the installation and chemical used. Operators should always take these data as a basis to operate calibrations under field conditions.								

Table XXVI. Flow from VRU standard odd number plate and with optional even number plate (after Castel, 1982 and Micronair, 1992).



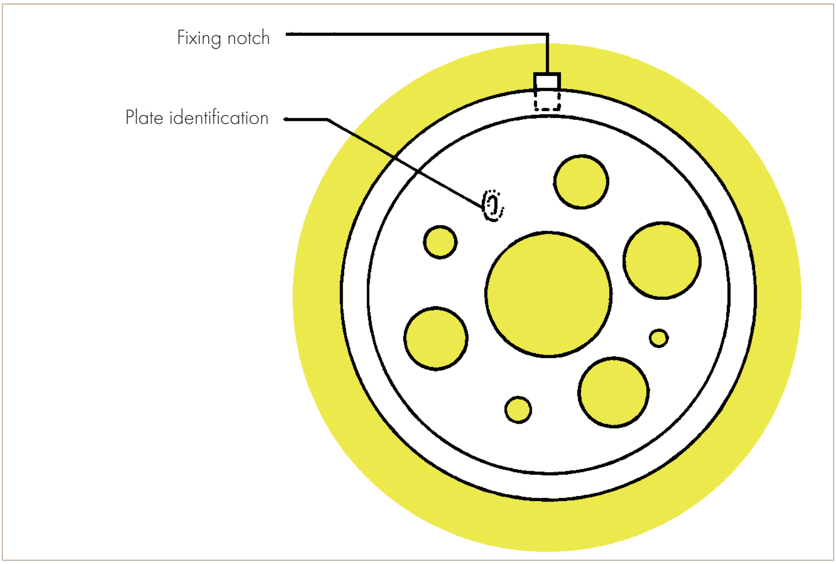


Figure 70. Fixed orifice plate (after Micronair, 1987).

The number on the knob of the VRU are aligned as follows:

8	**9**	**10**	**11**	**12**	**13**	**14**
1	**2**	**3**	**4**	**5**	**6**	**7**

For example, by turning the knob to the pair of numbers 13 and 6, one of the two following cases is possible:

- If the orifice plate "E" is fixed, then the orifice nº 6 is selected.
- If the orifice plate "O" is fixed, then the orifice nº 13 is selected.

Identification	Manufacturer's reference	Orifice
O	EX 194/O	Odd numbers
E	EX 194/E	Even numbers
L	EX 194/L	1 to 7 numbers
H	EX 194/H	8 to 14 numbers
B	EX 194/B	None

Table XXVII. Alternative VRU orifice plates and their manufacturer references.
The flow must always enter the side of the VRU. This forces the selector plate against the orifice plate. Should the VRU be incorrectly installed with the chemical entering the end, the plates would be forced apart and an erratic flow would result.

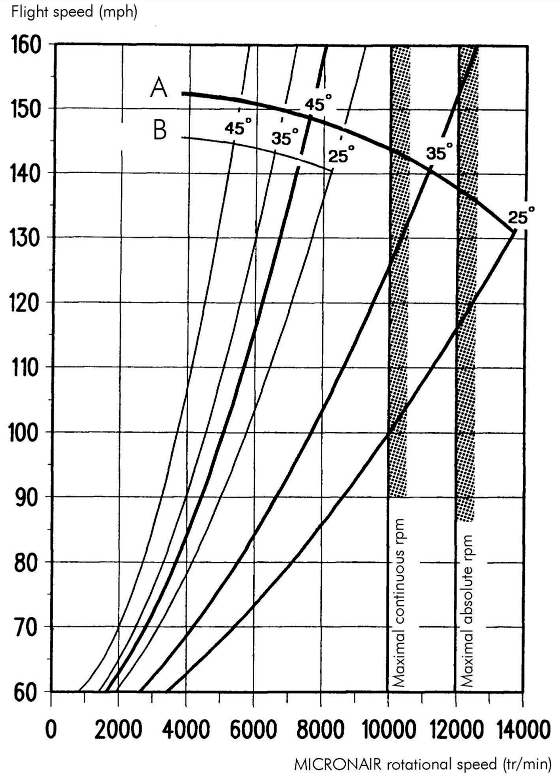
During calibration the viscosity of the formulation should be taken into account. The influence of this factor on the flow variation is as important as pressure variastion. Besides viscosity varies with the temperature. It is generally admitted that

viscosity decreases by half if the temperature rises from 20 to 40° C. **The maximum viscosity compatible with the use of Micronair is 50 centistokes**.
In the Micronair system the working pressure varies from 20 to 50 psi (around 1.4 to 3.5 bars). Its influence on the flow remains within these limits. In contrast to hydraulic energy nozzle, the pressure does not influence droplet size.
The total output from the aircraft in litres per minute is divided by the number of atomizers to determine the output from each atomizer.

Each VRU should be checked and cleaned periodically. Should it be necessary to dismantle the unit, follow manufacturer's instructions.

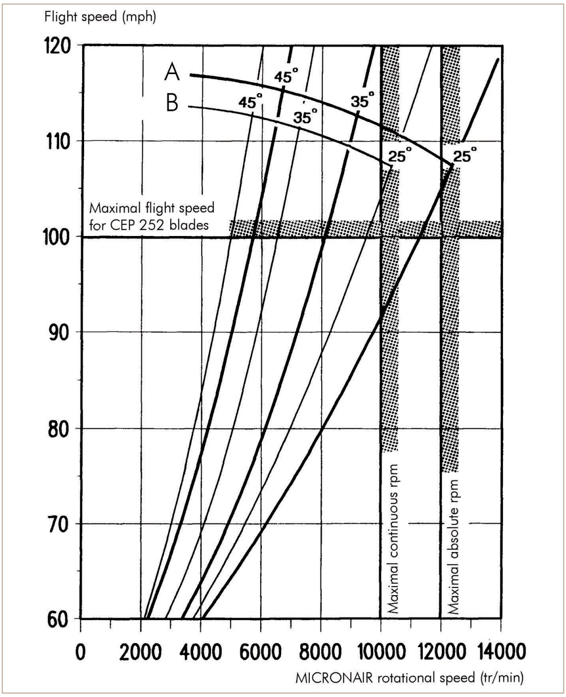
Fan blades and droplet size

Micronair atomisers are supplied with different fan blades according to different flying speeds of aircrafts (fig. 71), suitable for air speeds between 75 and 150 mph (120-240 km/h). For faster aircrafts, it may be necessary to shorten the blades, provided they keep a uniform size and the weight (a variation in weight less than 0.5 g is acceptable). Slower aircrafts and helicopters require longer fan blades. The manufacturer can supply them on demand.



A: dry; B: water (20 l/min).

Figure 71. Graph of rotational speed *vs* air speed for AU4000 fitted with CBP289/2 with 3.7″ standard blade (after Micronair, 1991).



A: dry; B: water (20 l/min).

Figure 72. Graph of rotational speed *vs* air speed for AU4000 fitted with CBP252/2 with 4.9″ standard blade (after Micronair, 1991).

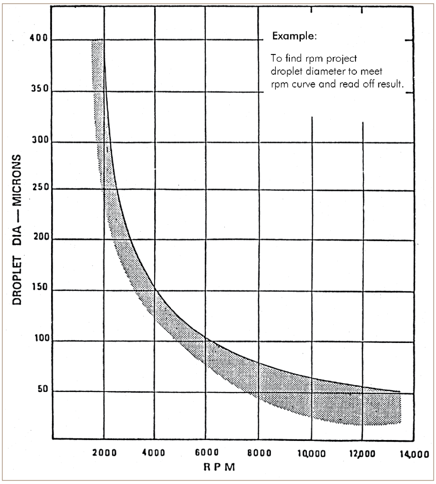


Figure 73. Graph of droplet size vs. rotational speed (after Micronair, 1986). The droplet size may vary or be reduced with many oil-based and ULV formulations as shown by the shaded band.
A check should always be carried out with the actual chemical being used.

Micronair atomisers are designed to produce a uniform droplet spectrum as possible, with a VMD less than 100 microns. The mean size of droplets produced by an atomiser is determined by the rotational speed of the gauze (fig. 73). As the gauze is turned by the fan blades in the airstream, the speed of rotation is controlled by both air speed and the blade angle. The air speed is determined by the type of aircraft and the spraying operations, hence **the droplet size is controlled by the setting of the fan blades**.

Having established the correct rpm, it is necessary to determine the appropriate blade angle setting to produce this rpm at the operating airspeed (fig. 71 and 72). For AU4000, the angle is shown in degrees over the range of 25-45 degrees, which is the normal operating range. These are marked **dry** and 20 l/min, corresponding to an atomiser spraying no (or very little) chemical and 20 l/min respectively. An increase in the volume of chemical flowing through the atomiser results in the atomiser slowing down. Greater power is required to break up the liquid into fine droplets. Consequently, it is necessary to set the fan blades to a smaller angle to speed up the fan to the required level when spraying higher volumes (fig. 74).

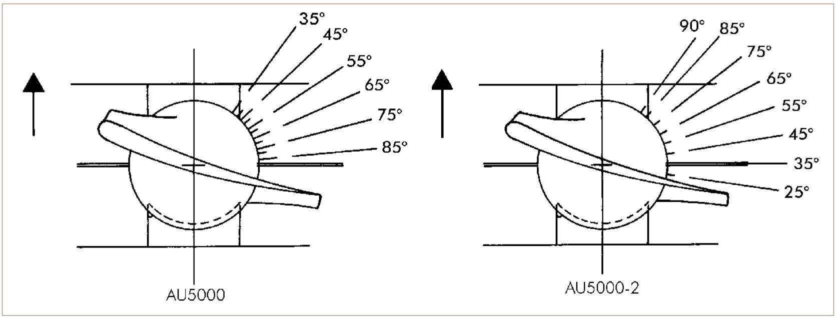


Figure 74. Adjusting blades angle for Micronair spray heads AU5000 and AU5000-2 (after Micronair, 1897).

The viscosity of the liquid being sprayed also has an influence on the rotational speed on the atomisers. Viscous formulations tend to reduce the rotational speed and hence to produce larger droplets. In general, ULV formulations will tend to form larger droplets than water-based LV formulations at the same rotational speed. Therefore, when spraying viscous chemicals or high outputs it is required to raise the power of atomisers to keep a relevant rotational speed. **It should be noted that there is a maximum continuous rotational speed for each type of atomiser.**

Application monitor

The application monitor is a complete monitoring system for any spray aircraft (fig. 75). Chemical flow is measured by a flowmeter turbine, which is connected to a microprocessor-based electronic unit. This takes the chemical flow rate, together with the swath width and ground speed of the aircraft and computes all the basic parameters of the spray operation.

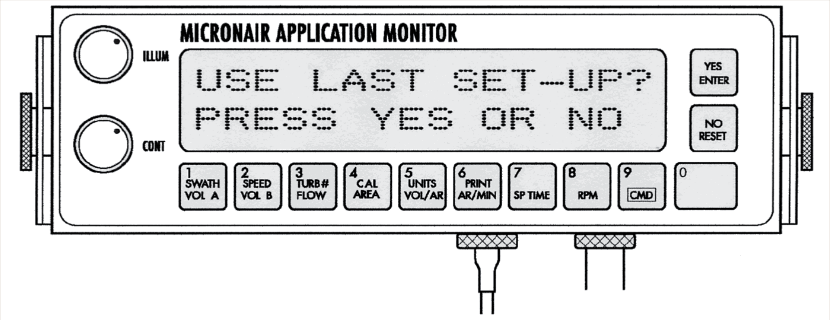


Figure 75. Front panel of application monitor (after Micronair).

The electronic unit incorporates a liquid crystal display and a touch keyboard. The key board is used to select the function shown on the display.
The application monitor can be calibrated to work with either of two flowmeter turbines. It is also programmed to operate with a printer, which may help to keep a daily record of every spray job.

Rpm indicator (tachymeter)

Given the close relationship between rotational speed of the atomiser and droplet size, it is very important that the pilot instantly visualize this datum. The application monitor may be used to measure the rotational speed of each of up to 10 atomisers.

Checks and maintenance

Normally the manufacturer provides an operator's handbook, corresponding to the installed system. It is of paramount importance to carefully read the entire handbook and follow its recommendations, regarding installation, operating procedures and maintenance. During intensive campaigns, it is necessary to thoroughly check all parts of the spray system before starting operations in every site and daily after the last morning flight. The main key points for regular checking are:

- Check the functioning of atomiser brakes and all atomisers before each flight.
- Ensure that all atomisers run smoothly. The only friction should be the small amount of drag from the V-ring seal. Do not continue to operate the atomizer if it does not run smoothly. Remove the unit, dismantle the bearing assembly and check the bearing and fits and clearances; particularly the two matched bearing spacers which should be identical lengths. Return the unit to the manufacturer if the solution cannot be found.
- Check that the spindle retaining the nut is tight and wire locked. Under no circumstances should the atomiser be operated if the nut is slack. If the atomiser is used with a loose nut, it is almost certain that the bearing or spacers will be damaged.
- If greased bearings are installed, ensure that they are greased regularly but not excessively. Overgreasing can cause heating and destroy the bearings.

- Inspect all gauzes for chemical deposits, damage or any conditions which may cause it to run out of balance. Gauzes should never be repaired in the field as they must be dynamically balanced after repair.
- Check that all fan blades are in good condition and are set to the correct angle for the work being undertaken. Replace any damaged blades and ensure that the clamp rings securing bolts are not overt-tightened. If the bolts are correctly tightened, it should be just possible to move the blades by hand. The gap between the clamp ring and the hub **must not be** completely closed.
- Inspect the diaphragm check valve for chemical leakage. This indicates a damaged or wrongly installed diaphragm.
- Ensure that all VRUs are correctly secured, set to the appropriate number and check that there is no evidence of chemical leakage.
- Check *application monitor* (if fitted) to be sure it is functioning correctly. Verify the accuracy of the reading by checking the volume of chemical sprayed against the actual area sprayed and the spray time.
- Should any vibration be noticed from the boom or atomisers, do not continue to operate. Reduce airspeed, apply atomiser brakes and land as soon as possible. Check for loose attachments, worn bearings, out of balance gauzes and insure all the blade settings are correct. Check that the hub, clamp, ring and gauze are correctly assembled and aligned.

B. Curtis Agri-Line ASC System

ASC-A10 Spray head

The ASC (Advanced Spectrum Controller) was designed in the United States, to operate at airspeeds which exceed 360 km/h (aircrafts) while continuing to excel in speeds as low as 55 km/h (small helicopters). It can deliver a wide range of outputs from conventional low volume to ULV spraying at 1 l/ha. The cage is fitted with graphite reinforced adjustable blade and heavy duty sealed bearing (fig. 17).

So far ten Agri-Line System is not commonly used for acridid control. But considering the design features asserted by the manufacturer, the ASC System is likely to be suitable for acridid control. Therefore we think that it deserves a place within equipment proposed for aerial applications in acridid control. Four models of ASC rotary atomisers are available: wind-driven for fixed wing, wind-driven for helicopters and electric-powered 12 volt DC and 24 volt DC.

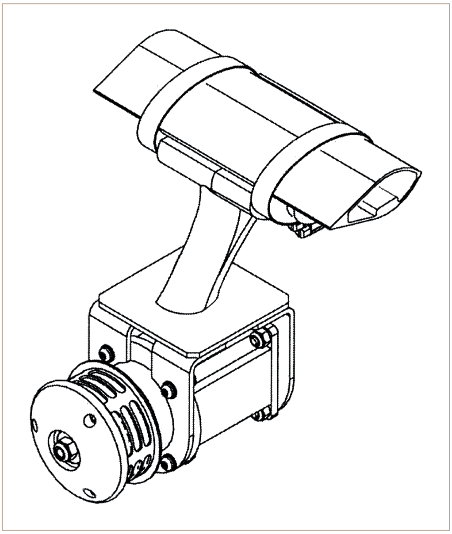
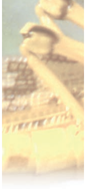


Figure 76. Curtis Dyna-Fog ASC-A20 cage.

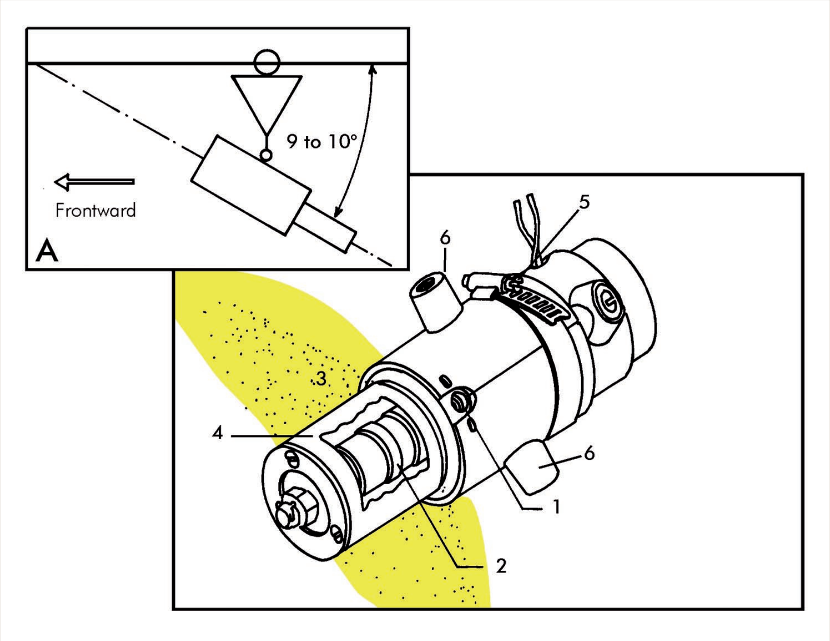


ASC-A20 spray head

It is electrically-powered. Feature blushless CD motor, double balanced with heavy duty sealed bearing. It is available in 12 and 24 volt version. The ASC-A20 is designed to equip helicopters. (fig. 76). The atomiser weight is 1.7 kg each.
The A20 atomiser produces a very tight droplet spectrum that is suitable for controlled drift spraying. Since this spray head uses blushless motor technology and a closed loop motor control circuit, atomiser speed can be accurately controlled so that virtually no variation is present during operation. The normal operating speed of ASC-A20 is 25,000 rpm and each atomiser can be independently adjusted to produce required droplet spectrum.

C. Beecomist spray head

The Beecomist spray head is manufactured by Beeco Products Company (USA). It is very common in the USA and is frequently mounted on helicopters in Europe, Africa and Near East.



1: inlet; 2: deflector; 3: mist; 4: cage; 5: clamp collar; 6: fixing the cage to the boom.
A: layout of spray head with regards to displacement of the airplane.
Figure 77. Diagram of Beecomist spray head (after Quantick, 1985).

It is a rotating stainless porous cylinder (fig. 77). Power is supplied by a hydraulic or electric motor which runs under 12 or 24 volts and a strength of 10 to 20 amperes. In this case the generator should be capable of providing a power of 100 amperes at full charge.

Droplet size varies with the rotational speed of the atomiser. A filter and a check valve are required up stream.

The atomizers should be fixed on the boom so that they form a 9 to 10 degrees angle with regards to the horizontal setting of the boom.

D. Airbi spray head

The first version realised by the French company Airbi was made of a rotating cylinder fitted with wire brush. Droplet spectrum was acceptable but the brush favours crystallization of chemicals. Now the brush is replaced by a perforated cylinder (fig. 78) The spray head, including the motor, weighs 1,140 grams. Liquid is introduced through a distributor and, under centrifugal force it is evenly distributed along the cylinder. The assembly motor and cylinder is compact, watertight and tropicalized. Rotational speed varies from 2,000 to 12,000 rpm and flow rate from 0,250 to 12 l/min.

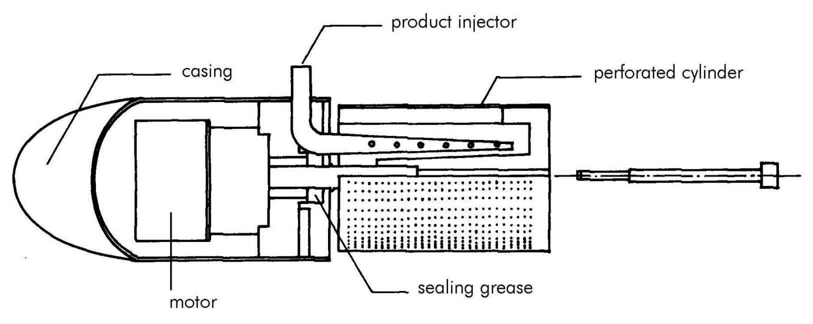
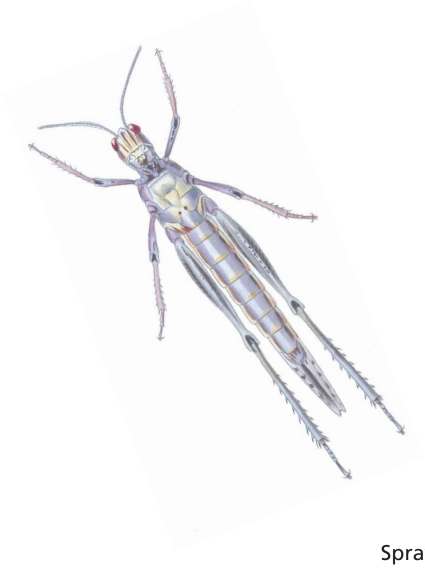


Figure 78. Cutaway of Airbi spray head (after Airbi, 1988).



Acridid Control Treatments

Intervention tactics

Intervention levels

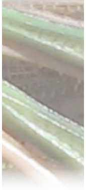
Intervention level depends upon the nature and the size of the target, the area to be treated and also local circumstances such as the quality and seasonal practicability of tracks, availability of aerial fleet, existence of field air strips, etc.
Three levels could be distinguished with regards to the choice of relevant equipment (tab. XXVIII).

Portable equipment

Hand-held ULV sprayers and motorised mist blowers could be ranked within this category. Hand-held ULV sprayers provide good quality spray but it is relatively irregular with motorised mist blowers. Therefore they need significant improvement so as to really be useful in acridid control.
For technical as well as social reasons, the use of hand-held ULV sprayers are to be preferred, at farmer level, for the control of grasshoppers, especially during the early stages of cereal crops or other food crops.
Considering preventive control of locusts, every survey team should have several hand-held ULV sprayers, besides vehicle-mounted equipment, so as to spray small areas as well as small size hopper bands.

Vehicle-mounted equipment

Until the 1980's, the exhaust nozzle sprayer was the only vehicle-mounted sprayer used in locust control.
Now, several spray heads are adapted, with more or less success, from aerial equipment. Several attempts showed that conditions which prevail in locust control, especially in dry tropical zones, are ruthless to any equipment which is not well-designed. Many stores of anti-locust services are cluttered with machines which were barely used but are already broken down, because their design does not meet the requirements or because they were delivered without relevant spare parts.



Uninterrupted infested area	Operators involved	
	Supervised farmers	Technical staff from plant protection services
Less than 1 ha	Hand-held ULV sprayers	Hand-held ULV sprayers
1 - 10 ha	Hand-held ULV sprayers	Hand-held ULV sprayers Motorised mist blowers
10 - 100 ha	Hand-held ULV sprayers Motorised mist blowers	Hand- held ULV sprayers Motorised mist blowers Vehicle-mounted sprayers
100 - 1,000 ha		Vehicle-mounted sprayers
1,000 - 10,000 ha		Vehicle-mounted sprayers Light aircrafts Helicopter with field support
10,000 - 100,000 ha		Light aircrafts Medium size aircrafts Helicopters with field support
More than 100,000 ha		Heavy cargo aircraft Several light aircrafts Medium size aircraft Helicopters with field support

Table XXVIII. Spraying technique alternative (after "Cube Expert", Prifas, 1988).

It should be stressed that **the properties which ensure success are robustness, simplicity of use and handling**.

When vehicle-mounted ULV sprayers are well designed, they can be used at all levels of acridid control. They play a major role in preventive and curative control of locusts, because it is possible to perform either blanket or barrier treatments.

Aerial equipment

Aircrafts play an important role at all levels of acridid control strategy.

In preventive locust control

Light aeroplanes with upper wings are valuable for extensive surveying. Flight surveys over susceptible areas enables ground teams to correctly manage their displacements. These sort of actions should be routine and be part of the survey program and preventive strategy.

In curative locust control

When outbreaks are affecting large areas or when many infestations are scattered over large areas, it is necessary to promptly take action to deal with the situation. Aerial means including helicopters and aeroplanes should be mobilised for either survey or treatments.

Scouting for hopper bands

Frequently, at the onset of outbreaks, infestations consist of many scattered hopper bands. The ability to locate them depends upon topography, vegetation type, vegetation thickness, hopper instars and density. Note that *transiens* hoppers of the Desert locust are yellow bright and, when they roost on bushes, they are visible from afar.

It should be noted that when a hopper band is found in a place, it is almost certain that there are others in the surrounding zone and, if none is found it does not mean that there is not any.

An upper wing aeroplane could be used to spot large hopper bands on short grass zones, but using helicopters in this operation is more successful.

Scouting for adults

Searching for adults is tenuous at best. Sometimes, when there are many adults on the area above which aerial survey is underway, it might be possible to spot them flying against light. However efficiency of swarm hunting with fixed wing aircraft is very poor. Helicopters are more efficient in pastoral zones where nomads may be of great help.

In palliative locust control

Tracking and localisation of swarms

This operation consists of tracking swarms until dusk when they land for night. This enables control teams to intervene immediately if they are operating in the surroundings or early in the morning of the following day. Considering their great mobility, helicopters are more suitable than aeroplanes but they should be long range models.

To spot flying swarms, it is better to search for them when they fly swirling i.e. late in the morning and early in the afternoon. Aircraft should fly at low levels so that swarms could be seen on the horizon with the clear sky as the background. Under cloudy conditions the efficacy of this method is weak. Consideration should be given to the fact that a person cannot focus his attention for more than two hours. Four consecutive hours scouting might be required, but would be tiring.

Settled swarms are difficult to locate on large grassland areas such as the Sahel. There is some chance to locate them if the most probable settling place is known.

Flagging

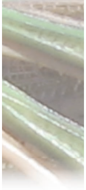
Normally swarm tracking teams operate flagging for aircrafts which spray the following morning. The ideal tool is a helicopter equipped with GPS which is capable of giving the exact position as well as the exact size of the target.

Treatment

During plague periods the main part of operations are made by means of aircrafts. At this level, except in mountainous areas, fixed wing aircrafts are the most suitable for spraying. Choice of aircraft type depends upon the size and the mobility of swarms. Ground support has a determining influence on the success of aerial operations.

Post treatment checks

The helicopter is the ideal tool to execute this necessary operation. Post treatment checks are all the more necessary since equipment and chemicals involved are important.



In grasshopper control

Aircrafts of various categories were used for controlling grasshoppers, from heavy cargo aeroplanes (Douglas DC7) to microlights.

Heavy cargo could be useful within integrated operations like French "Écoforces" in 1989. Due to high operating costs, they are less desirable for spraying. Microlight turned out to be too fragile to operate in Sahelian and Saharan conditions where the atmosphere might be subject to sudden changes.

Actually, among fixed wing aircrafts, light aeroplanes are the most adapted to the requirements of grasshopper control. They have better efficiency regarding treated area (more than 2,000 ha/day) and lower cost-in-use.

The great advantage of helicopters in grasshopper control lies in their versatility. They might be used for survey, spraying and post treatment checks. Running costs of this type of aircraft varies with the specifications of the model used, good range being a major factor.

Types of acridid control treatments

Blanket coverage

It consists of treating a given infested area so as to achieve a uniform coverage. This is obtained by spraying according a track spacing shorter than the swath width, so that spray from each pass overlaps the deposit of the previous.

Treating locust swarms

Settled swarms should be treated early in the morning when cool temperature force them to remain on the ground. Trying to spray flying swarms is not efficient as well dangerous (obstruction of filters and loss of visibility due to locust impacts on the windscreen).

Chemicals used against swarms kill locusts mainly by direct contact which means that insects should be touched by droplets. Hence the spray quality is essential to ensure acceptable locust mortality.

With vehicle-mounted and aircraft applications, track spacing varies with wind speed and the chemical used from 100 to 300 m.

When knockdown insecticides are used, any re-infestation of a given zone, requires a new treatment even if it is covered with vegetation:

- a few hours after application of pyrethroids,
- 24 hours after application of malathion,
- 48 hours after application of chlorpyriphos.

Treating hopper bands and grasshoppers

It is preferable to use stomach action insecticides. The residual activity of the product and the vegetation thickness, determine the maximum track spacing which, in any case, should not exceed 400 m (fig. 79). It might be:

- 100 m, as maximum with contact action insecticides (pyrethroids, *Metarhizium*);
- 200 m, as maximum with stomach and contact action insecticides (chlorpyriphos, imidacloprid);

- 300 m, as maximum with stomach action insecticides (IGRs, fipronil).

When vehicle-mounted sprayers are used, it is recommended to adopt a relevant approach with regards to the wind direction and the hoppers march (fig. 80 and 81).

Barrier treatments

Background

Barrier treatments were initiated in the former Soviet Union to combat Desert locust hopper bands in Central Asia (Kortkih & Starostin, 1945). Recommendations were then made to treat strips of 25-30 m and leave 45-50 m. Large scale tests were carried out in Indo-Pakistan desert during 1963 by the FAO Aerial Group of Operational Research, within a vast international program (FAO, 1968; Castel, 1982). Two objectives were pursued. The first was to treat rapidly Desert locust hopper bands, infesting very large areas, so that it will be possible to be able to intervene faster than the velocity of plague extension. The second was to decrease cots as much as possible. The principle was to use wide track spacing by rising progressively the emission height. Developing drift spraying technique was furthered by optimal use of lateral wind and the height efficacy and residual activity of dieldrin, an organo-chlorine insecticide. Ever since, barrier spraying offered to locust control, a determinant strategic factor. Gradually this technique was brought into general use, which allowed successful control of hopper bands in outbreak sources, before dispersal of initial swarms. Therefore barrier spraying became a valuable tool to locust plague prevention strategy.

Since 1986, dieldrin was banned in locust control, because of its high toxicity, long lasting persistence and adverse ecological effects. The problems with dieldrin in locust control were topics of concern log before the withdrawal of the product. A project was carried out by the FAO (FAO-Swedish Fund-In-Trust) from 1971 to 1977 (FAO unpublished report) to find an effective insecticide as a substitute to dieldrin; however no product for barrier treatment was discovered. Since the banning of dieldrin, all insecticides used in locust control are mainly contact active with only one or a few days of residual activity. They must be applied directly on locust. For effective control, it was thus necessary to detect a spray every hopper band, with blanket coverage. Hence it was almost impossible to prevent widespread outbreaks (e.g. Desert locust upsurges in 1987 and 1993).

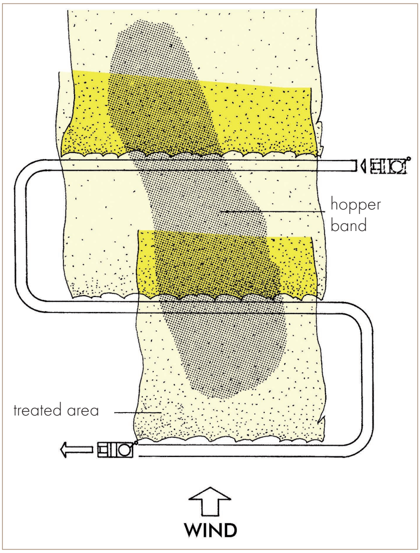


Figure 79. Layout of basic procedure of blanket treatment of a hopper band with vehicle-mounted sprayers.

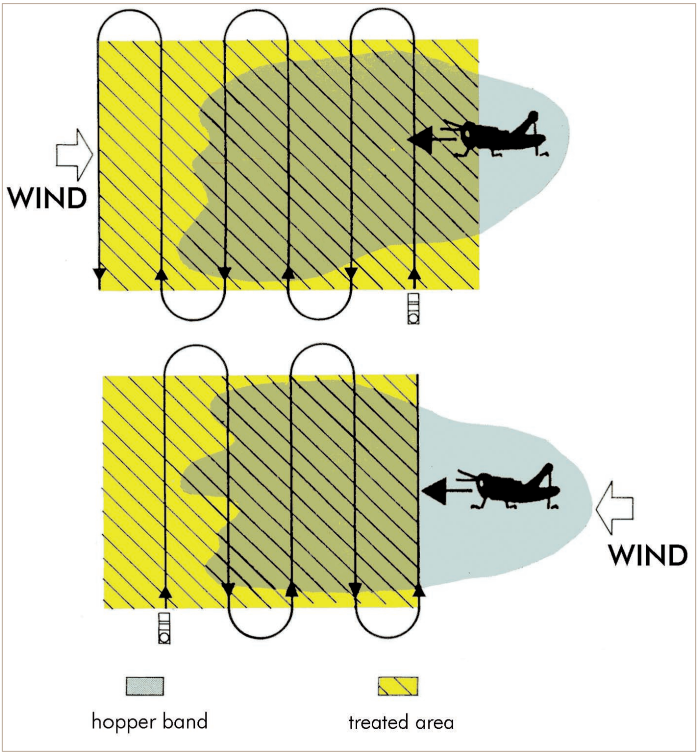


Figure 80. Treatment of a hopper band marching upwind (after Steedman, 1988).

In 1992 and 1993, "barrier" treatment trials were performed with diflubenzuron and triflumuron (benzoyl urea chemical family, also called IGR family) in Madagascar (Scherrer & Rakotonandrasan, 1993; Cooper *et al.*, 1995; Tingle, 1996). In late 1993, fipronil, a compound of a new chemical family (phenyl-pyrazols) was proposed, by a company, as a substitute for dieldrin. The laboratory tests showed very good efficacy against locust, with good residual activity (Buttler & du Perez, 1994; Kriel, Buttler & du Perez, 1994; Megenasa & Muinamia, 1994). By the end of 1994, field tests with blanket coverage performed in Mauritania against Desert locust under Saharan conditions, established that the compound had excellent efficacy via both contact and ingestion, with effective residual activity (Rachadi *et al.*, 1995). In October and November 1995, the Desert locust that occurred in Mauritania offered an opportunity to successfully perform a barrier treatment trial with fipronil.

Definitions and principles

The barrier technique adopted by locust control operators over several decades, is based upon drift spraying, whereby the wind speed, emission height and droplet size have a substantial influence on the actual swath width and shape. With the

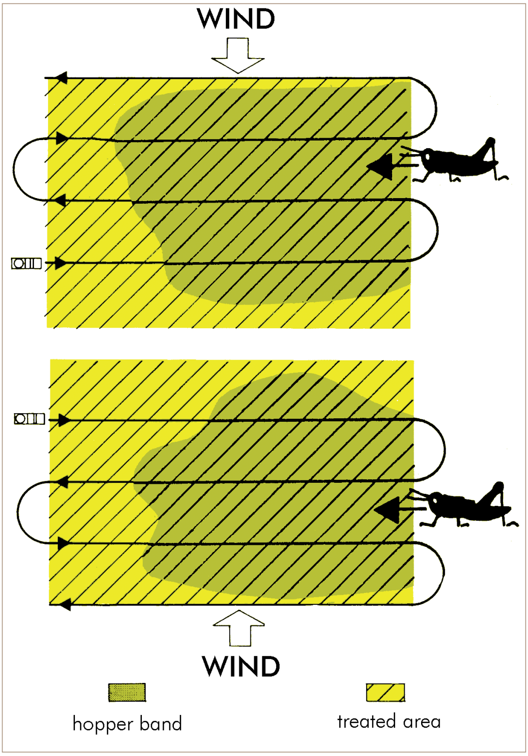
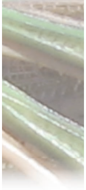


Figure 81. Treatment of a hopper band marching crosswind (after Steedman, 1988).

barrier technique (fig. 82), track spacing precludes overlapping swaths. Droplet size and deposit rate decrease downwind and the deposit is not uniform. Sudden variations of wind direction or wind speed, variation of track spacing or the emission height, differential shading by hills or dunes are all application factors which may contribute to deposit variability and thus the variability of actual swath width. As such, it is possible to determine where a swath starts but it is relatively difficult to know exactly where it ends. Downwind displacement and the time a droplet is exposed to this effect, i.e. the emission height and droplet size. Castel and Balmat (1979) adopted an approach for applying dieldrin with a track spacing of 1,500 m and flying height of 50 m. Locust Handbook (Steedman, 1988) recommends 3,000 m as safe track spacing with both aerial and exhaust nozzle spraying. The method was first called “vegetation baiting”, then “poisoning the vegetation” and finally the term “barrier spraying” was adopted.

During all the 1960’s and 1970’s, when Desert locust control operators made recommendations concerning spray parameters, they gave neither a dose per hectare within the barrier nor the width of the strip serving as suitable barrier. Castel (1987) recommended spraying when the wind is rather strong so as to obtain the widest swath as possible. The parameters were 10 to 15 l/km of a dieldrin for the exhaust nozzle (depending on the vehicle speed) and 10 to 15 l/km for aircraft



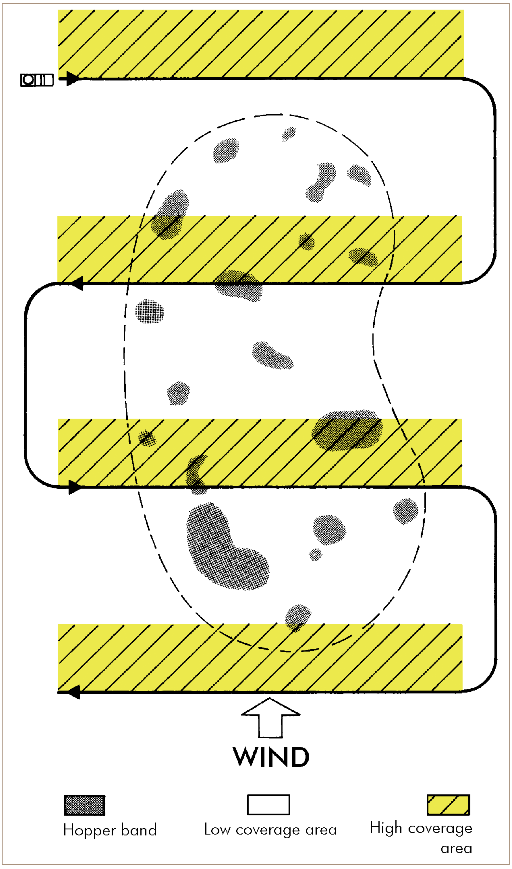


Figure 82. Layout of barrier treatment procedure (after Steedman, 1988).

(depending on the flying speed), with an emission height of 20 to 50 m with a wind from 1 to 4 m/s.

It did not matter whether the dieldrin was applied on relatively highly dosed strips over vegetation or generally over the whole area. Since the dieldrin accumulates in the locust bodies, the effect will be much the same if the insect acquires a lethal dose gradually as if it eats enough treated vegetation to kill it quickly. However Castel and Balmat (1987) recommended spraying swaths as wide as possible to avoid highly dosed strips in order to prevent endangering nomad livestock. Thus sprays were performed at a 50 m emission height and a wind speeds 5 to 7 m/s. Overall treatment did not, of course, rely on band movement and so did affect young nymphs, which died easily, as well as the older ones in marching bands. This was particularly relevant to hatching that may occur after spraying. The key of barrier treatment with the dieldrin is its persistence which permitted uneven coverage, wide track spacing and which avoids the need for respraying.

By the end of the 1990's, when IGRs and the fipronil were introduced in locust control, barrier treatment became again possible. Unfortunately, skilled and experienced operators in barrier spraying had already left the field for many years and the concept of this technique was not well understood by temporary practitioners. Thus, a variant method which did not entirely correspond to the original technique, was adopted and also called "barrier". In trials conducted in Madagascar with IGRs (Scherrer & Rakotonandrasana, 1993; Cooper *et al.,* 1995; Tingle, 1996), strip spraying was adopted as a barrier technique. In Wyoming, USA, an approach called RAAT (Reduced Agent Area Treatment) involved applying low rates of insecticides in intermittent swaths to control grasshoppers was tested. The objective was to achieve a more economically and environmentally sound pest management strategy in comparison to traditional blanket application at high rates.

Since Desert locust plagues were causing tremendous damage, developers of barrier treatment were mainly motivated by, curbing and subsequently preventing plagues. Environmental benefits of barrier treatments were noticed and welcomed. They were not specifically sought.

Performing barrier treatments with new compounds and equipment

Barrier treatment as it was practised during the 1960's (Courshee & MacDonalds, 1963; FAO, 1968; Castel & Balmat, 1982; Steedman, 1988) according to parameters which varied for aerial applications:

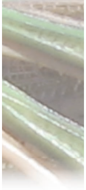
- emission height: from 10 to 50 m,
- track: from 1,000 to 3,000 m (sometimes even more)
- wind speed: from 1 to 4 m/s.

When barrier treatments were performed by means of exhaust nozzle sprayer, the track spacing might be as wide as 1,000 m (Castel, 1987) under a wind quite strong (5 to 7 m/s). Under lower wind forces track spacing were reduced but never below 500 m. In this case, they were resulting in coverage which was more irregular than coverage seen with barrier spraying.

It should be noted that correct execution of barrier treatment is linked to chemical specifications and equipment performance.

A. Problems linked to the specifications of modern compounds

Modern products which might be used as chemical agents for barrier treatments belong to two chemical families: phenyl-pyrazols (fipronil) and benzoyl-ureas or insect growth regulators (IGRs) (diflubenzuron, teflubenzuron, hexaflumuron). It should be noted that, to be eligible for barrier treatment, an insecticide should comply with four requirements: to be **highly toxic** for acridids, to have at least **3 weeks residual activity**, to kill mainly by **ingestion** and induce an **accumulation effect**. Each of these requirements is necessary but not sufficient to ensure the success of the method. The first condition is necessary for ensuring a good efficacy at a low dose, the second and the third to ensure the killing of nymphs which are touched by spray droplets.



Insect growth regulators

IGRs disrupt chitin synthesis, a basic cell constituent, which induce death of acridids while moulting. Accordingly IGRs are effective only against nymphs. As well as this specificity on young forms of insects, IGRs are effective only through stomach. They are reputed to have a residual activity of over four weeks but they do not seem to have a cumulative effect (Cooper *et al.*, 1995). This might be a disadvantage since insects are likely to metabolize sub-lethal doses (Neuman & Guyer *in* Cooper *et al.*; Sherrer & Rakotonandrasana, 1993). However this phenomenon might be mitigated by the fact that nymphs are less mobile when they ingest IGRs. Another feature of IGRs is the variability of their toxicity against locust, i.e. the efficient dose varies with compounds (FAO, 1995).

Among IGRs, diflubenzuron, triflumuron and teflubenzuron were more or less deeply tested for barrier applications, but so far, not all of them have been tested in operational conditions. However, even those which were successful are likely to allow barriers as wide as 1,000 m. The maximal track spacing for each compound should be determined by tests in operational conditions.

Fipronil is a compound of phenyl-pyrazols, a new insecticide family. Its effectiveness in barrier applications was proved by tests against hopper bands of Desert locust. A barrier treatment trial in operational conditions, showed that track spacing as wide as 2,000 m can be highly effective against Desert locust hopper bands (Rachadi & Foucart, 1996), without any modification to the spraying system of an aircraft usually used in locust control. The product had strong knock down effect together with a sustained stomach action. A residual activity over three weeks was revealed by tests performed in field conditions (Rachadi *et al.*, 1995). **From a strict technical point of view, fipronil fully complies with barrier treatment requirements.**

B. Problems linked to spray equipment

The volume of application (in l/ha), for barrier treatment, is markedly lower than that of blanket (0.075-0.150 l/ha compared to 0.5-1 l/ha). On the other hand, the volume per km to be applied does not sensibly vary and is usually between **10 and 15 litres per km.** This is independent from the vehicle or aircraft speed and an adaptation of each type of equipment is required. Thus, the approach is not the same according to aerial or ground equipment.

Aerial equipment

For blanket coverage, an aircraft flying at 130 km/h should have an output of 16.66 l/min, to apply 1 l/ha according to 100 m track spacing. For barrier, with the same flying speed, the output should be 32.5 l/min and 15 l per km for a track spacing as wide as 2,000 m. In the first case two spray heads can **ensure a good droplet spectrum**, while, in the second case, a minimum of four are required. In the first case, a 600 litre tank is emptied out within 36 min in the first case and 18 min in the second. This aspect should not be underestimated since a good droplet spectrum is a *sine qua non* condition for a successful barrier treatment.

Ground equipment

Barrier treatments with ground equipment are submitted to the same requirements as for aerial. However, considering overdosing risks, it is preferable to use less concentrated formulations. Besides, emission height is lower and thus track

spacing should not exceed 1,500 metres. At a speed of 10 km/h, the **output might be 1.5-1.5 l/min** for 10 to 15 litres per km.
The exhaust nozzle sprayer (ENS) was widely used successfully, for barrier treatments, in preventive and curative control for almost three decades. Castel (1987) reported that droplet VMD was more than acceptable (**50 to 120 microns**) when mechanical and spray calibrations were correctly executed, even when the output was high (0.4-4.5 l/min but more frequently 1.5-3 l/min). Despite assertions of some people, disadvantages of ENS do not come from its failure to ensure correct droplet spectrum but from the difficulty to sustain mechanical and flow calibrations**.** The largest drawback of ENS was that its correct use requires very skilled and well-supervised people.

Now the vehicle-mounted electrical sprayers supplant advantageously the ENS. They can provide outputs consistent with barrier application requirements together with good droplet spectrum. However, in view of their possible emission height and new pesticide specifications, track spacing should not exceed 1,000 metres.

C. Problems of real coverage in barrier spraying

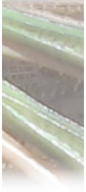
Droplet dispersal, i.e. the coverage, depends upon several factors which are globally determined by the spray parameters. Thus, droplet size, emission height and wind speed influence swath width. Even when basic parameters (output, displacement speed, track spacing droplet generation and emission height) are correctly calibrated, many uncontrollable factors may interfere:

- **Wind speed** which is never steady, in force and in direction. Wind force may vary from one to four times during the same treatment.
- **Topography.** Droplet deposit is affected by relief elements such as sharp contours, bare soil, slopes, etc.
- **Plant cover**. Trees, shrubs and bushes intercept droplets, leaving unsprayed, parts of grass layer, which exacerbates deposit variation.
- **Thermal currents** may be originated by surface heating due to insolation or advection or combination of the two. Air warmed by the ground beneath does not rise as continuous stream but rather than a series of bubbles.
- **Ground treatments** are affected by variations of forward speed, due to obstacles and vegetation along spray runs.

D. Problems related to the environment

It should be noted that the actual swath is almost always larger than 1,000 m. Areas totally free from active ingredient are very rare. The objective of the inventors of this method is precisely to cover, with small amount of pesticide, the largest area as possible. Thereby, the area covered with a dose that can kill the insect at first contact is very small. Most often it varies from 15 to 30 % of the total area (Van der Valk, 1988; Rachadi & Foucart, 1996). Dieldrin was thus applied according to sub-lethal coverage on the largest part of the area to be protected. Sub-lethal coverage was possible with dieldrin owing to its residual activity together with its cumulative effect.

The concern for the preservation of non-target fauna and the specifications of modern compounds (IGRs and phenyl-pyrazols) argue for a new approach of



barrier technique with the objective of leaving uncontaminated a part of the target area. The principle is to provide wide spacing between swaths and thereby offering the basis for relatively fewer non target impacts. It seems likely that the environmental harm of applying an insecticide with a 3-week residual to just one third to one half of the land will be less than blanketing the area with an insecticide having a 3-day residual (Lockwood *et al.*, 2000).

Practice of treatments

Basic calibrations

Necessity of calibration

Experienced locust control operators used to say that inefficacy of treatment is almost always due to inappropriate or lack of calibration and not to bad product. (fig. 83). Even if this possibility should not be discarded *a priori*, it should be admitted that a lack of information and unskilled staff is frequent. It is not rare to meet operators and technicians supplied with equipment without any document for maintenance or calibration instructions. Learning becomes then a question of imitation or by trial and error. Sometimes, when documents are available, they are so confusing that they are useless.

In this book, the study of VLV and ULV spray equipment is favoured, because other spray techniques are seldom used in acridid control. Besides, mechanical matters were not thoroughly developed comparatively to calibrations and different aspects of maintenance routines which deserve priority.

Before starting to spray, any equipment, aerial, ground or vehicle-mounted, should be submitted to **basic calibrations. Failure to do so will undoubted result in a drop of efficacy of the treatment.** The spray operation supervisor has to ensure that all calibrations are correctly executed.

Three basic interdependent factors which determine the amount or volume of application per hectare are:

- **Flow rate or output**. It is monitored by an orifice plate, an orifice nozzle, a combination of the two or a flow regulator.
- **Forward speed**. There are three scales of speed, from 3.5 km/h for knapsack sprayers, 5 to 15 km/h for vehicle-mounted sprayers to 90 to 250 km/h for aircrafts. Calibrations of forward speed will therefore be achieved respectively on 100 m, 500 m or 1 km (as a minimum) for aircrafts (fig. 84).
- **Distance between spray runs or track spacing**. It depends on droplet size, emission release and wind speed.

These three factors are closely interdependent, because if one is modified, one or both of the others should be modified in order to apply the same amount of formulation per hectare.

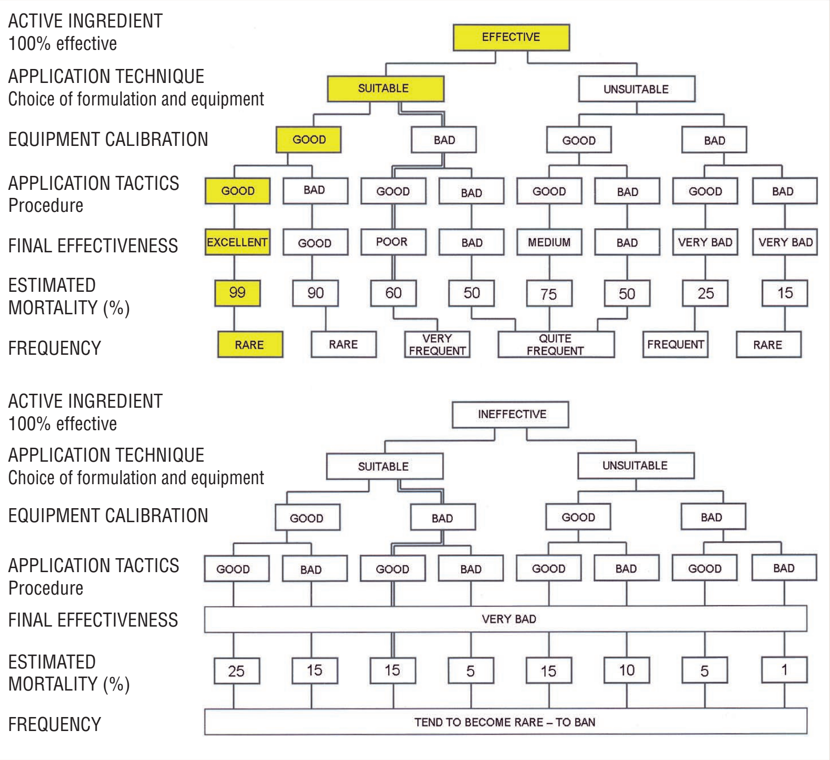


Figure 83. Frequency of bad calibrations of ground equipment in acridid control (after SAS Letter, 18/89, Prifas, 1989).
Ineffectiveness of treatments are mainly due to bad calibrations.

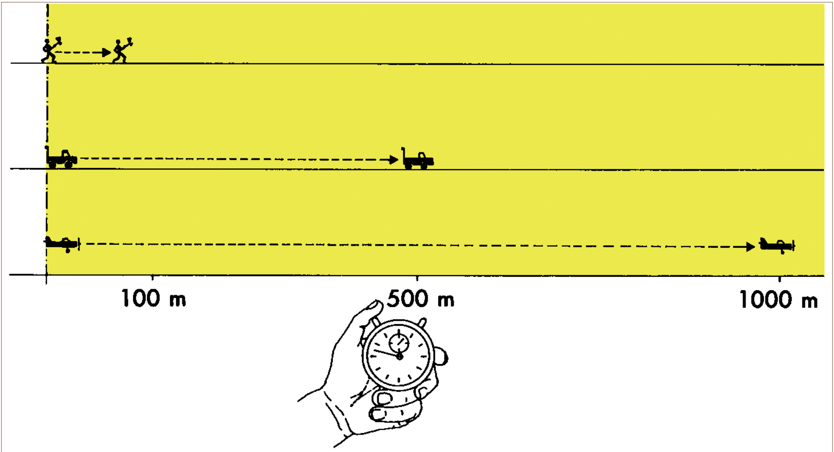
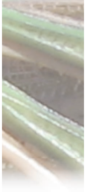


Figure 84. Suitable distances for speed calibrations of different spray equipment.



Even if a sprayer is equipped with a sophisticated flow regulator, a manual flow check is always useful. Checking the output is essential every day before the first spray and before spraying another formulation even if it has the same content as that formerly used and also when another equipment is used even if it is the same as that used before. Besides, **calibration and output checks should be performed with a liquid having a comparative viscosity to that of the formulation to be used or at least checked with it**.

Basically, manufacturers provide, with each model of equipment, a document (manual or handbook) which details the appropriate calibration and maintenance procedure. Unfortunately those documents are often missing when they are really needed. However with some experience and some resourcefulness, it is still possible to perform acceptable calibration, even when manufacturer's document is missing.

Usually, in acridid control, the volume of application is determined beforehand, because it depends on the dose and the formulation available. To apply as accurately as possible the determined volume of application, it is required to adjust the three mentioned basic factors.

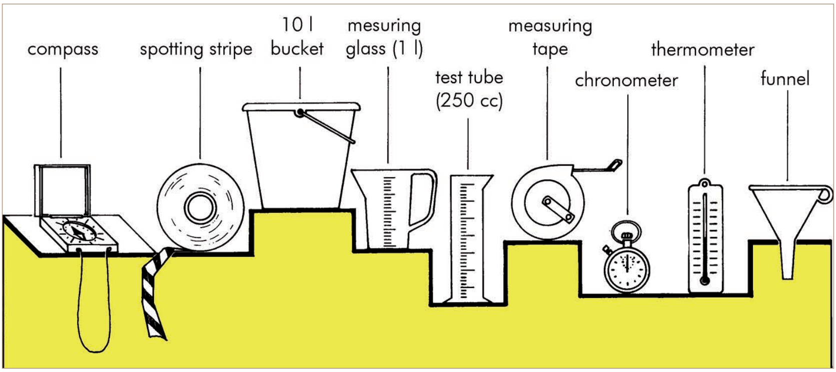


Figure 85. Tools and devices to perform correct calibrations and checking.

Tools for calibration

To perform correctly the basic calibrations of these sprayer and other checking, it is necessary to provide a minimum of tools and various instruments of measures tools and utilities (fig. 85):

- a 10 l plastic bucket, preferably with pouring lip. Checking spray system of an aircraft requires a container for each spray head;
- a calibrated beaker (1 l volume);
- measuring tube of 250 ml;
- a small and a large funnel;
- a chronometer or a stop-watch;
- a thermometer to measure the air temperature;
- a toolkit adapted to the equipment used;

- various implements such as clean and dry rags, papers, small paint brush, signalling tapes, yellow flags, etc.
- a compass;
- a measuring tape or better, an odometer (fig. 86).

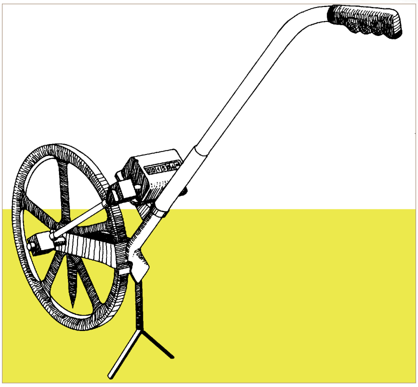


Figure 86. Odometer.

Preliminary calculations

Prior to practical task of calibrating, it is necessary to determine the target calibrations. The following examples of calculations explain how to derive these values.

3. How to determine the forward speed

The basic parameters:

S = forward speed (km/h)
F = flow rate or output (l/min)
T = track spacing (m)
V = volume of application (l/ha)

When the output and the track spacing are determined, it is possible to calculate the forward speed by using the following formula:

$$S = 600 \times F / T \times V$$

***1st example**: if you are going to apply a formulation of fenitrothion at one litre per hectare (V) using a hand-held ULV sprayer with a flow rate of 0.6 l/min (F) and if the track spacing (T) is 12 m, what will be the walking speed (S) of the operator?*

By using the formula the result is:

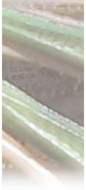
$$S = 600 \times 0.06 / 12 \times 1 = 3 \text{ km/h}$$

***2nd example**: to apply the same volume for application (V) using a vehicle-mounted sprayer, the output (F) of which is 1.4 l/min and the track spacing (T) is 70 m. In this case what will be the forward speed (S)?*

$$S = 600 \times 1.4 / 70 \times 1 = 3 \text{ km/h}$$

***3rd example**: to spray a similar infestation with the same product at the same quantity (V), an aircraft sprays 25 l/min (F) according to 120 m track spacing (T). What should be the flying speed of the aircraft?*

$$S = 600 \times 25 / 120 \times 1 = 125 \text{ km/h}$$



Recapitulation of the basics

The basic parameters should be determined before starting any spray (tab. XXIX):

- The volume of application (**V**), expressed in litres per hectare.
- The flow rate (output) (**F**) in litres per minutes.
- The forward speed (**S**) in kilometres per hours.
- The track spacing (**T**) in metres.
- The emission height (**H**) of droplets in metres.
- The lateral wind speed in metres per second.
- The distance (**D**) over which droplets drifts before hitting the ground.
- The sedimentation velocity of droplets.

Basic parameters	Units	How to determine the parameters
1 - Volume of application (**V**)	litres per hectare	V = 600 x F / T x S
2 - Flow (**F**) rate or output	litres per minute	F = S x T x V / 600
3 - Forward speed	kilometres per hour	S = 600 x F / T x V
4 - Track spacing	metres	T = 600 x F / S x V
5 - Emission height	metres	H = D x Vs / U
6 - Distance of drift	metres	D = H x U / Vs
7 - Wind speed	metres per second	Anemometer or Beaufort scale

Table XXIX. Recapitulation of the basic parameters of controlled drift spraying.

Treatments with portable sprayers

This category of equipment is composed of motorized knapsack mist blowers and hand-held ULV sprayer.

Portable sprayers are normally adapted to the physical capabilities of a human adult. Their weight should not exceed 14 kg in full charge so that they may be normally carried by a person working normally under warm conditions. The monitoring system of the flow rate should be designed according to the speed of a person walking normally unhurriedly (one metre per second). In light of these two elements, the problem is different when spraying with a hand-held ULV sprayer compared to motorized knapsack mist blower, since the weight of the latter is an additional factor of spray unevenness.

Basic calibrations

Calibration and checking flow rate

Although the basic principle of the flow rate calibration is the same, the operating method is different for each model of equipment, therefore an appropriate method will be developed for each type of equipment.

4. How to determine the flow rate (F)

When the volume of application (V), the forward speed (S) and the track spacing (T) are known, the following formula can be applied:

$$F = S \times T \times V / 600$$

***1st example**: a formulation with Malathion is to be applied at 5 l/ha (V) with a knapsack mist blower. Considering that the walking speed (S) of the operator is 3.5 km/h and the track spacing (T) is 30 m, what should be the output (F)?*

$$F = 3.5 \times 30 \times 5 / 600 = 0.875 \text{ l/min}$$

***2nd example**: the same formulation is used against the same target (V = 5 l) by means of a vehicle-mounted sprayer which has a forward speed of (S) 12 km/h. What should be the output (F) if the track spacing is (T) is 75 m?*

$$F = 12 \times 75 \times 5 / 600 = 7.5 \text{ l/min}$$

***3rd example**: a helicopter is going to spray the same target the same product (V = 5 l). Considering that the flying speed (S) during treatment is 140 km/h and the track spacing (T) 100 m, what should be **the global** the flow rate (F)?*

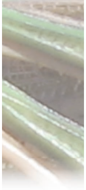
$$F = 140 \times 100 \times 5 / 600 = 116.66 \text{ l/min}$$

Calibration of forward speed

Steadiness of forward speed depends, among other things, on the ability of each operator to monitor his walking. It is evident that the walking speed will be difficult to control as the sprayer is heavy, which is the case with knapsack motorized mist blowers. Portable sprayers are designed for an adult i.e. walking slowly at more or less 1 metre per second. Every operator should adjust his steps in accordance with this walking speed.

Two scenarios are possible: either the operator **adjusts his walking steps to a determined speed and maintains this pace or calibrates to his normal speed keeping in mind that he should not modify it afterward**. Then he adjusts the output accordingly.

In all cases, measurements and calibrations should be performed by an operator while carrying a sprayer with the tank half full.



5. How to determine the track spacing (T)

When the forward speed (S), the output (F) and the volume of application (V) are known, the following formula can be applied:

$$T = 600 \times F / S \times V$$

***1st example**: A hand-held ULV sprayer is used to apply a formulation of Chlorpyriphos-ethyl at a volume of 3 l per ha (V). Considering that the output (F) is 0.160 l/min and the walking speed (S) of the operator is 3.8 km/h, what should be the track spacing (T)?*

$$A = 600 \times 0.16 / 3.8 \times 3 = 8.42 \text{ m, rounded up to } 8.5 \text{ m}$$

***2nd example**: a vehicle-mounted sprayer is going to apply a formulation at 1 l/ha (V). Considering that the flow rate (F) is 1.75 l/min and the forward speed (S) of the vehicle is 11.5 km/h, what should be the track spacing (T)?*

$$T = 600 \times 1.75 / 11.5 \times 1 = 60 \text{ m}$$

***3rd example**: An aircraft is applying a formulation of IGR at 0.5 l/ha (V). Considering that the total output (V) of the four spray heads is 16 l/min and the flying speed (S) 145 km/h, what should be the track spacing (T)?*

$$T = 600 \times 16 / 145 \times 0.5 = 132 \text{ m}$$

First case: the walking speed is predetermined, usually 1 m/s (3.6 km/h)

- In a field having that same topography as that to be treated, delimit and mark a 60 m straight line.
- Measure the time it takes to walk across the marked distance. Start at ten metres before the first mark, so as to walk steadily when passing. Make a “top” while starting the chronometer or the stop watch, when passing the starting mark. Do not slow down when approaching the second mark but first make the end “top” when passing, then stop.
- Read on the chronometer the time; it should be 60 seconds. If it is not suitable, repeat the operation by modifying the walking rhythm accordingly, until the time equals 60 seconds.
- Once the correct speed is acquired, train to keep it.

Second case: walking speed of the operator is to be adapted to the other parameters

Preparation tasks are the same as for the first case:

- In a field having the same topography as that to be treated, delimit and mark a 100 m straight line.
- Start walking 10 m before the first mark. Keep walking steadily without haste. The chronometer is activated and stopped as indicated above.
- Read the time on the chronometer and record the speed.
- Repeat the operation five times and calculate the average of the results.
- Determine the average time for walking over 100 m and the corresponding walking speed: this is **the calibrated walking speed of the operator.**

Determining track spacing

With knapsack mist blowers, track spacing depends on the range of the air stream i.e. the power of the machine. When using controlled drift spraying with these types of equipment, track spacing depends on the emission height and wind the speed during treatment (see § ULV formulations p. 34).

The **minimum emission height** for drift spraying is one metre above the vegetation. The **maximum emission height** depends upon the specifications of the equipment. It is 2.5 m when using hand-held ULV sprayers (fig. 87) and 3 to 4 m with mist blowers equipped with an appropriate droplet generator.

Time walk across 100 m	Walking speed	Time walk across 100 m	Walking speed
120.0	3.0	90.0	4.0
116.0	3.1	87.0	4.1
112.5	3.2	85.7	4.2
109.0	3.3	83.7	4.3
106.0	3.4	81.8	4.4
102.0	3.5	80.0	4.5
100.0	3.6	78.2	4.6
97.3	3.7	76.5	4.7
94.4	3.8	75.0	4.8
92.4	3.9	73.4	4.9
90.0	4.0	72.0	5.0

Table XXX. Time to walk across 100 m and the corresponding walking speed of the operator.

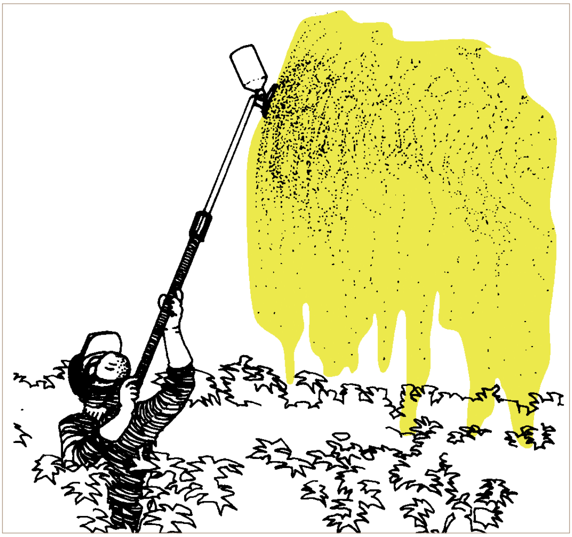
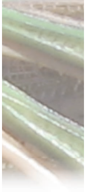


Figure 87. Maximum emission height with hand-held ULV sprayer (after Matthews, 1985). The emission height for portable sprayers, varies generally from 1 m (above emerging plants) to 7 m (with mist blowers, air flow upwards). Track spacing varies from 5 to 60 m, according to the emission height and the speed of lateral wind (fig. 88 and tab. XXXI).



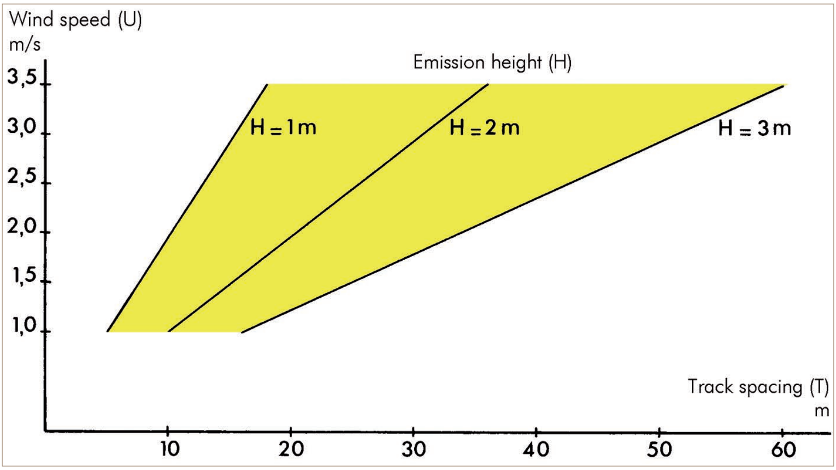


Figure 88. Maximum track spacing against wind speed and emission height for the use of portable sprayers.

Emission height (H) m	Wind speed U (m/s)	Droplet size (Φ)								Maximal track spacing T (m)
		40	50	60	70	80	90	100	120	
1*	1.0	21.0	13.0	9.5	7.0	5.5	4.0	3.5	3.0	5.0
	1.5	32.0	20.5	14.0	10.5	8.0	6.5	4.5	4.0	8.0
	2.0	42.5	27.0	19.0	14.0	11.0	8.0	7.0	6.0	10.0
	2.5	53.0	34.0	23.0	17.5	13.5	11.0	9.0	7.0	14.0
	3.0	63.5	41.0	28.5	21.0	16.0	13.0	10.0	8.0	16.5
	3.5	74.0	48.0	33.0	24.5	19.0	15.0	12.5	10.0	20.0
2*	1.0	42.5	27.0	19.0	14.0	11.0	9.0	7.0	505	10.0
	1.5	63.5	41.0	28.5	21.0	16.0	13.0	11.0	8.5	16.0
	2.0	85.0	54.5	38.0	28.0	22.0	17.0	14.0	11.0	21.0
	2.5	106.5	68.0	48.0	35.0	27.0	22.0	18.0	14.0	27.0
	3.0	127.0	82.0	57.0	42.0	33.0	26.0	21.5	17.0	32.0
	3.5	149.0	95.5	67.0	50.0	38.0	31.0	25.0	20.0	38.0
3**	1.0	63.5	41.0	28.5	21.0	16.0	13.0	11.0	8.5	16.0
	1.5	95.5	61.5	43.0	32.0	24.5	19.5	16.0	12.5	24.0
	2.0	127.0	82.0	57.0	43.0	33.0	26.0	21.5	17.0	32.0
	2.5	149.0	95.5	71.5	53.0	41.0	33.0	27.0	21.0	37.0
	3.0	191.0	132.0	85.5	64.0	49.0	39.0	32.5	25.5	48.0
	3.5	233.0	143.0	100.0	74.5	57.5	46.0	37.5	29.5	60.0

* Hand-held ULV sprayers.
** Knapsack mist blowers.

Table XXXI. Drift of droplets and the maximum track spacing to be adopted with portable sprayers (Rachadi, 1989).

Motorised knapsack mist blowers

Calibration and checking flow rate

Two scenarios may be encountered depending whether or not it is possible to disconnect the liquid circuit and collect formulation in separate receptacle.

First case: the liquid circuit cannot be disconnected.

- Set the sprayer on a stable area so that the filling orifice is horizontal.
- Fill the tank with the formulation up to filling orifice neck or to the bottom of the filter gauze.
- Set the flow regulator to the appropriate position or place the required nozzle.
- Start the engine and accelerate until the blower reaches its nominal rotational speed.
- Open the control valve, let the formulation flow until the whole circuit is full.
- Close the control valve, stop the engine, refill the formulation tank up to the orifice neck.
- Re-start the engine and accelerate until it reach its normal speed for spray.
- Open the control valve and, at the same time, start the chronometer (or a stop watch). Let it spray for one minute. Close the control valve at sixty seconds time.
- Stop the engine.
- Set the sprayer at the initial position.
- Refill the tank. The added quantity should be carefully measured.
- If the added quantity is significantly different from that expected, modify accordingly the flow regulator and repeat the operation.
- When the result is close to that expected (more or less 5%), make a few more tests and adopt their average.

Second case: it is possible to disconnect the liquid circuit.

- Put a few litres of the formulation into the tank.
- Disconnect the formulation hose from the airflow nozzle and make sure it can pour into a bucket or a measuring cylinder.
- Start the engine and accelerate until the blower turns at its normal speed.
- Set the flow regulator at the position corresponding to the required flow rate.
- Open the control valve and let the liquid flow so that the circuit is bled and full of liquid.
- Close the control valve, empty the cylinder into the formulation tank. Do not stop the engine.
- Again put the formulation hose into the measuring cylinder or the bucket.
- Open the control valve and at the same time start the chronometer.
- Let the formulation flow for one minute and, at sixty second time, close the control.
- Measure the liquid collected.
- If this quantity is significantly different from that expected, adjust the flow regulator accordingly and repeat the operation.
- When the quantity of liquid collected is close to that expected (more or less 5%), repeat the operation 3 times to be sure that the flow rate is steady.

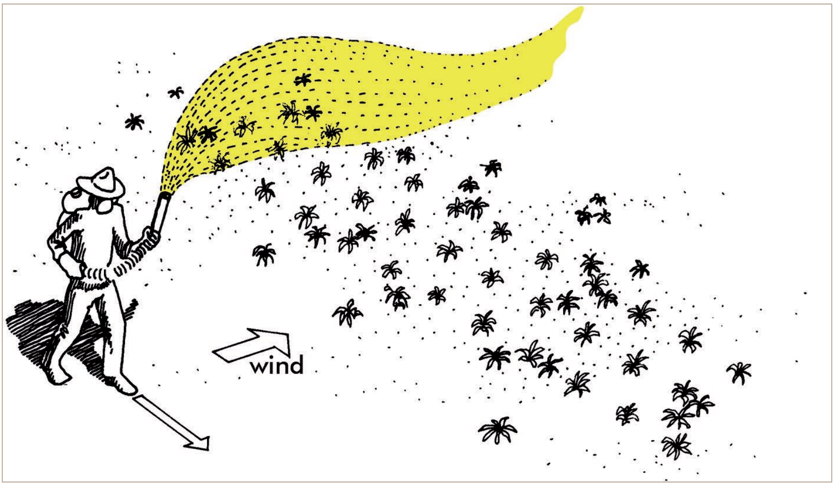


Figure 89. Mode of displacement for controlled drift spraying with motorized mist blowers. The operator walks straight forward at a regular speed.

Spraying

When using ULV technique to spray 1 l/ha it is useless to fill up a 10 l tank, since an operator cannot spray 10 ha nonstop. Spraying should not start unless all the basic parameters have been determined and the calibrations performed.

- Delimit by flags the field to be treated.
- Begin the spray at the side downwind.
- In optimal conditions the wind direction is perpendicular to the spray runs (fig. 22). To have a constant watch of wind direction, it is advisable to provide a permanent source of smoke or a flag of light plastic.
- Walk forward, at regular speed, according to the calibrated speed (fig. 89). Care should be taken to avoid the natural tendency to spray rocking from side to side. It would be better if the spray nozzle is fixed upward (fig. 36).
- Never spray during stops. Close the control valve even if the engine is not stopped.

Hand-held ULV sprayers

Flow rate calibration

The output depends on the flow restrictor orifice and the viscosity of the formulation. Temperature variation also influences the output, since high temperature may quicken the flow and *vice versa*. Therefore, the output should be checked every time if one of the parameters has changed (new formulation, volume of application, walking speed or track spacing) or when there is a dramatic change in temperature. Anyhow, the output should be checked under working conditions, at least once before starting to spray at each site. For flow rate calibration, the following procedure may be applied:

- Make sure the sprayer works correctly.
- Choose and fit the appropriate restrictor nozzle (or feed nozzle).

- Fill the bottle with the formulation to about half a litre, by using a funnel.
- Place a measuring cylinder or a container on a stable surface.
- Remove the atomiser disc and turn over the sprayer.
- Wait until the flow is steady and then let the liquid flow into an empty container (or measuring cylinder) for one minute. It is very important to trigger the stop watch at the moment the liquid begins to flow into the empty container.
- Measure the liquid dispensed. If the quantity collected in one minute is significantly (more or less than 5 %) different from that expected, change the nozzle and repeat the preceding procedure.
- If the output is close to that expected (more or less 5%), repeat the operation two more times and adopt the average.

Choosing emission height

The minimal emission height above the vegetation is one metre. If the weather is calm or when the vegetation is thick, the sprayer may be held so that the spray head is about 2.5 m above the vegetation (fig. 87).

Choosing track spacing

The most **appropriate track spacing** depends upon the behaviour of the target (see § Target and active ingredient, p. 7) and the mode of action of the active ingredient. The actual track spacing will be imposed by versatile factors which are vegetal cover shape, formulation, wind speed, possible emission height and droplet size.

The ideal wind speed varies from 1 to 3.5 m/s. Below 1 m/s, drift is not sufficient and, above, droplets may fly beyond the target zone and the coverage might be sparse.

As a matter of fact, with these sprayers, almost all the parameters are imposed and only track spacing leaves some flexibility to the operator. The recommendations given in table XXXI take into account an overlapping of three swaths (fig. 90), under blanket treatment conditions. When spraying pesticide with long residual activity, track spacing might be twice as wide as indicated in the table.

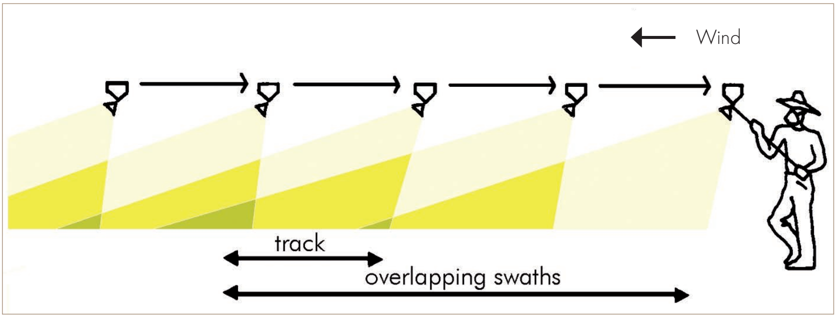
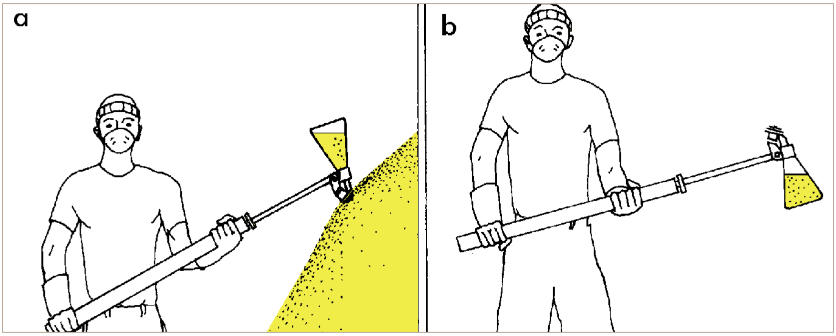


Figure 90. A diagram of showing track spacing with overlapping swaths (after Matthews, 1985).



a: treatment position, the bottle should be vertical; b: no spray position.

Figure 91. Position of hand-held ULV sprayer.

Spraying

Globally, the tactic is the same as described in § "Choosing emission height". Basic calibration being fulfilled, it is however necessary to carefully execute the following tasks:

- Check that the correct number of batteries is being used for ULV application.
- Check direction and wind speed.
- Fill the bottle and seal it carefully. Hold the sprayer in the stand-by position (fig. 91).
- Before starting, remove the disc cover and put it away in a secure place.
- Stand at the starting point to begin the first spray line. This point is situated at the top of downwind edge of the land to be treated. Start inside the land, at a distance equivalent to a track spacing.
- Hold the sprayer head downwind so that the wind takes droplets away from the operator when spraying.
- Adjust the spray head to the correct emission height and set it so that the flow nozzle is close to vertical position.
- Switch on the sprayer and check if spray disc is spinning correctly (with some experience an operator can identify the correct sound). The rotational speed can also be checked by using a tachometer.
- Wait until the motor reaches its maximal rotational speed. Never touch the disc when spinning or hold the spray head too close to the operator.
- Turn the sprayer so that the bottle upside down (fig. 91) and start walking immediately at the rhythm acquired during walking speed calibration. The flow nozzle should be maintained at vertical position. Hold the sprayer slightly to the rear so that the operator walks away from the spray mist. **Care should be taken to restrain the tendency to lower the sprayer downwards or to slow down when meeting concentrated spots of acridids**.
- Walk straight towards the flag which should be placed in a position where it can be seen by the operator while spraying.
- At the end of a spray pass, turn over the sprayer so that the bottle is underneath of the spray head (fig. 91), then switch off the sprayer.
- Move upwind to the starting point of the next spray pass. **Count the number of steps corresponding to the track spacing.**

- Walk until the end of the spray pass and repeat the operation as described above.
- When several operators spray the same field, every one should be away from the spray mist of the other, and never walk through any part of the field that has been sprayed (fig. 92).

Maintenance

Good and regular maintenance is a condition to ensure a good longevity of equipment and spray accuracy. A tool kit and some instruments are required to perform the maintenance operations.

Maintenance tool kit (after Ciba-Geigy, 1984)

- two screwdrivers (medium and small size),
- a Philips screwdriver (medium size),
- a metallic brush or abrasive cloth,
- a small paintbrush,
- a pair of tweezers,
- a pair of wire stripping pliers,
- a pair of flat nose pliers,
- a vibrating wire tachymeter ("Vibratak")
- a voltmeter or a torch or a torch lightbulb and small wire (fig. 93).

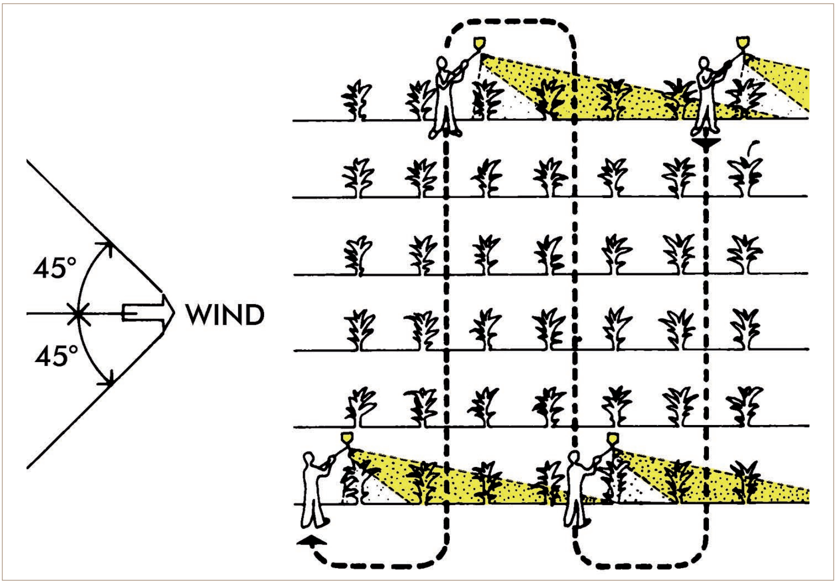
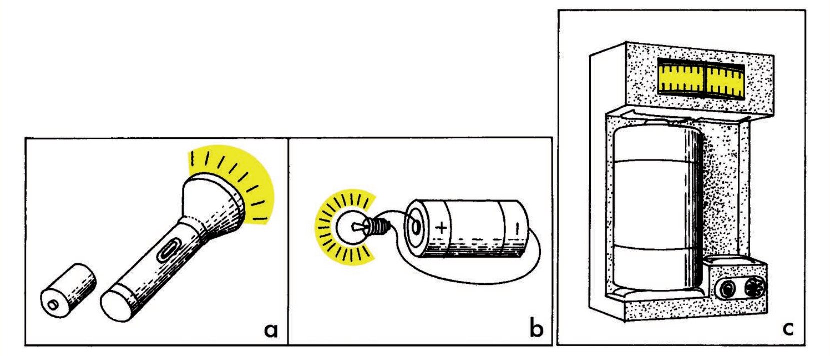


Figure 92. Diagram of the operator advance during treatment with hand-held ULV sprayers (after Matthews, 1985).

Checking utilities

- implements and tools described above,
- some clean rags,
- a roll of soft paper (toilet paper could be good),
- soap,
- a container of diesel or solvent.



a: by means of a torch; b: by means of a torch bulb; c: by means of a voltmeter
Figure 93. Checking battery condition of hand-held ULV sprayers (after Ciba-Geigy, 1984)

Checking the good working order of the sprayer

To ensure a good working order of the sprayer, regular checks are necessary:

- frequently check if the flow is correct. Regularly verify that the nozzle orifice is not obstructed. When required remove impurities by means of a fine stem. **Never blow into the nozzle with the mouth**.
- **Periodically check the rotational speed of the spray disc**. It should spin at its nominal speed. When possible use a pocket tachometer such as "Vibratak". In case of malfunction, search for the cause and the remedy (tab. XXXII).
- As soon as a rotational slow down is noticed, **battery condition** should be checked (fig. 93). A set of batteries can provide enough energy for 3 to 4 hours of intermittent use.

Maintenance routine for hand-held ULV sprayers

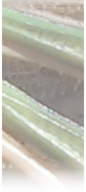
- On the whole, manufacturer's recommendations should be followed, particularly those concerning maintenance, as well as instructions for troubleshooting (tab. XXXII).
- Before starting to spray, it is recommended that all the checks mentioned above be performed.
- Make sure the spray liquid never contacts the motor axis. To prevent this from occurring, always switch on the motor before turning down the spray head and always turn up the spray head before switching off the motor.
- Follow the manufacturer's procedure for placing or removing the battery set. When the latter has run down, it is also essential to change the whole set composed by identical elements. Never mix old and new batteries, this could harm the sprayer motor.
- At every end of day dispose of the remaining formulation in the original container and flush the sprayer with diesel or kerosene.
- Meticulously clean the bottle, the disc, the motor shaft by means of a dry cloth or clean soft paper.
- Before storage for a long period, the spray head should be disassembled and cleaned and re-assembled according to manufacturer's instructions.

Symptom	Possible cause	Remedy
Atomiser disc does not spin or spins intermittently	Batteries worn out	Replace batteries
	Batteries not fitted correctly	Correct position or replace if necessary
	Atomiser disc rubbing on motor base plate or motor shaft bent	Replace disc or motor if necessary
	Electrical contacts broken or corroded	Replace if necessary
	Electrical terminals and contacts encrusted	Clean scrupulously
	Motor jammed or wear	Give back sprayer to supervisor or replace motor
Atomiser disc spins slowly	Batteries are worn out	Replace batteries
	Atomiser disc rubbing on motor base plate or motor shaft bent	Replace disc or motor if necessary
	Disc or motor plate encrusted	Clean by solvent and a dry cloth (follow manufacturer's instructions)
Insecticide does not flow or flows irregularly	Feed nozzle incorrectly fitted	Refit properly
	Feed nozzle obstructed	Unblock and a thin stem and soak in soapy water. Never blow in the feed nozzle with mouth
	Incorrect position of the spray head	Adjust spray head position
		Check that seal inside cap is in place and undamaged
		Check if bottle is screwed correctly or undamaged
Big drops leak from the disc	Disc encrusted or damaged	Clean disc or change it
	Disc not fixed properly	Fit disc properly
	Feed nozzle incorrectly fitted	Refit properly
Liquid leaks from the bottle holder	Bottle cap not screwed correctly or damaged	Screw cap properly or change it if necessary
	Feed nozzle is incorrectly fitted	Refit properly

Table XXXII. Troubleshooting pertaining to hand-held ULV sprayers.

Treatments with vehicle-mounted sprayers

Vehicles intended for carrying anti-acridid sprayers should be adapted to their purpose. First, the engine should be diesel as gasoline vehicles are not acceptable because the gear box does not allow suitable speed range.



Basic calibrations

Flow rate calibration

Although every model is provided, by the manufacturer, with a specific calibration procedure, it is possible to emphasise some general principles which enable operators to perform correct calibration if the calibration document is missing. Two cases may be encountered.

First case: the liquid can be collected at the spray head (Dyna-Jet and Ulvamast). The procedure is as follows:

- Place the vehicle on a stable flat area. Put the handbrake.
- Make sure the drain valve is closed.
- Pour a few litres of the liquid into the formulation tank.
- Place a clean bucket underneath the spray head.
- Place the orifice restrictor plate and/or adjust the flow control valve.
- If the power is provided by the vehicle, start the vehicle engine; otherwise start the sprayer engine.
- For spinning spray heads, **start only** the formulation pump so as to allow the liquid to turn in a closed circuit; then adjust the pressure according to manufacturers' indications related to the model.
- Open the flow control (or switch on the pump) and let the liquid to flow a few seconds into the bucket so that the circuit is bled.
- Close the flow valve (switch off the pump), then pour back the liquid into the formulation tank.
- Again put the bucket underneath the spray head and open the flow valve (switch on the pump, **do not run the spray head!**). The moment the liquid begins to flow from the spray head **trigger the stop watch**. Let the liquid flow for sixty seconds; close the flow valve (switch off the pump) at the right moment.
- Measure the liquid collected.
- Compare to the expected output and adjust the flow regulator accordingly.
- Repeat the operation until the output is close to that expected. The difference should be less than 5%. When the output is acceptable, repeat the operation three times to confirm the result.

Second case: the liquid cannot be collected at the spray head (autonomous mist blowers). The procedure is as follows:

- Stop the vehicle on a stable and flat area where pollution risks are minimal (especially in case of accidental spill of formulation). The sprayer head should be directed downwind so that the spray mist would not contaminate the working place.
- Check that the drain valve is closed.
- Fill up the formulation tank.
- Start the sprayer engine.
- Start the formulation pump and let the liquid to flow in an internal circuit. Adjust the pressure according to the manufacturer's indications related to the model.
- Open the flow valve and spray a few seconds to allow the liquid to fill the circuit and expel air from it.
- Close the flow valve.

- Refill the formulation tank. Notice the exact level of the liquid in the filling orifice.
- Open the flow valve and at the same time trigger the stopwatch. Let the liquid flow sixty seconds. Close the flow valve and stop the engine.
- Refill the formulation tank with a measured quantity of the formulation.
- Compare the added quantity with that expected and correct the flow regulator accordingly.
- Repeat the operation until the flow is close to that expected. When the output is acceptable, repeat the operation, to confirm the result and adopt the average as the flow rate.

Forward speed calibration

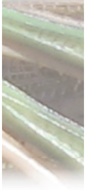
The great diversity of all terrain vehicles and their several ranges of forward speed (tab. XXXIII) impose forward calibration of each vehicle. But this is rather difficult since most of the vehicles are not equipped with an engine tachymeter nor with a hand accelerator. A calibration procedure is detailed hereinafter but results do not have acceptable accuracy unless vehicles are equipped with mentioned devices. It should be mentioned that speedometers of vehicles (km/h) are not accurate enough below 20 kilometres per hour.

Type of vehicle	Forward speed (km/h)				
	1st gear + reduction	2nd gear + reduction	3rd gear + reduction	1st gear	2nd gear
Land Rover 110 (diesel)	4.77	7.91	11.39	10.81	14.06
Mitsubishi L200 (diesel)	4.7	7.12	11.32	7.54	13.74
Toyota Land Cruiser (gasoline)	7.82	13.53		14.06	
Toyota Land Cruiser (diesel)	3.53	6.45	11.8	6.86	12.63

Table XXXIII. Average forward speed (km/h) of different vehicles according to their gear shifting (Rachadi,1989).

Two people are necessary to perform forward speed calibration: a driver and the spraying supervisor. Measurement instruments should be provided (fig. 85 and 86) i.e. a stop watch, an odometer or measure tape. During the operations the supervisor is seated in the cab on the **passenger** seat) holding the stop watch (fig. 84). The calibration procedure is conducted as follows:

- **Choose a flat area** where a 500 m distance can be easily delimited. A normal trail in the bush is suitable. However, rough path or tracks should be avoided.
- **Delimit a straight line of 500 m** by fixing a staff in each limit. **Be careful!** This operation should not be accomplished with the vehicle because, at this scale, the vehicle speedometer is not accurate enough; it would alter the basis of the calibration and thus the results.



- **Start running at about 50 m before the first staff** so as to run at regular speed when entering the delimited zone.
- **Adjust the acceleration** so that the engine runs at its normal speed; do not race it or run at too low speed. If the vehicle is equipped with a tachymeter, it is possible to spot the adequate engine speed. Once the correct engine speed is adopted, it should be kept during the whole tests and spraying operations. This is easy if the vehicle is equipped with a hand accelerator but rather difficult otherwise. The problem can however be mitigated by fitting a wedge under the pedal of the accelerator.
- **Start running** and shift into the chosen gear.
- **Adjust the engine speed** up to the chosen level. The vehicle should run steadily when it passes before the first shaft without varying the acceleration.
- **The passenger triggers the stopwatch** at the very moment he passes in front of the first staff.
- **The vehicle cross the 500 m** without varying its forward speed. Do not vary the gear nor the engine speed.
- **Do not slow down** when approaching the second staff but pass it keeping the same speed.
- **The passenger stops the stopwatch** at the very moment he passes in front of the shaft.
- **Stop the vehicle**, read the time and compare with the reference data (tab. XXXIV).
- **Repeat the operation** three times and adopt the average (fig. 94).
- **Calculate the corresponding speed** (km/h).

It clearly appears that only double gear vehicles (with reduction) should be used in acridid spraying; others are too fast to be suitable.

Vehicule trademark: Type: Model:

Calibration distance (D) (km):

Gear	**Time (sec)** [min. x 600 = sec]			**Mean Time** (t) (sec)	**Speed** (km/h) [V = D x 3 600/t]
	1st trial	**2nd trial**	**3rd trial**		
1st gear + reduction					
2nd gear + reduction					
3rd gear + reduction					
1st gear					
2nd gear					

Figure 94. Forward speed calibration form for carrier vehicles.

Time	Speed (km/h)	Time	Speed (km/h)
6 min 00 s	5.00		
5 min 46 s	5.20	2 min 56 s	10.20
5 min 33 s	5.40	2 min 53 s	10.40
5 min 21 s	5.60	2 min 50 s	10.60
5 min 10 s	5.80	2 min 47 s	10.80
5 min 00 s	6.00	2 min 44 s	11.00
4 min 50 s	6.20	2 min 41 s	11.20
4 min 41 s	6.40	2 min 38 s	11.40
4 min 33 s	6.60	2 min 35 s	11.60
4 min 25 s	6.80	2 min 33 s	11.80
4 min 17 s	7.00	2 min 30 s	12.00
4 min 10 s	7.20	2 min 28 s	12.20
4 min 03 s	7.40	2 min 25 s	12.40
3 min 57 s	7.60	2 min 23 s	12.60
3 min 51 s	7.80	2 min 21 s	12.80
3 min 45 s	8.00	2 min 18 s	13.00
3 min 40 s	8.20	2 min 16 s	13.20
3 min 34 s	8.40	2 min 14 s	13.40
3 min 29 s	8.60	2 min 12 s	13.60
3 min 25 s	8.80	2 min 10 s	13.80
3 min 20 s	9.00	2 min 09 s	14.00
3 min 16 s	9.20	2 min 07 s	14.20
3 min 11 s	9.40	2 min 05 s	14.40
3 min 07 s	9.60	2 min 03 s	14.60
3 min 04 s	9.80	2 min 02 s	14.80
3 min 00 s	10.00	2 min 00 s	15.00

Table XXXIV. Time to cross 500 m and corresponding speed of all terrain vehicle.

Determining track spacing

The actual track spacing will always be the result of a compromise between possibilities and constraints. The possibilities are determined by natural factors (wind speed thermal conditions) and technical factors (emission height and droplet spectrum, etc.). These constraints impose certain limits on the potential possibilities. The pesticide mode of action and the volume of application are very important, but the nature and thickness of the plant cover and gear combinations of the vehicle play a bit role as well.

The emission height generally ranges from 2 to 10 metres. It should be determined at the beginning of each day and when of the key factor is changed i.e. permutation of the vehicle or change in the wind speed. If the wind subsides, it is always preferable, whenever possible, to rise the emission height rather than shortening the track spacing (fig. 95).

For the sake of optimization and within the limits of sprayer specifications, in most cases, track spacing varies from 100 to 400 m for blanket coverage, 400 to 1,000 m for irregular coverage and 1,000 to 1,500 m for barrier (tab. XXXVI).

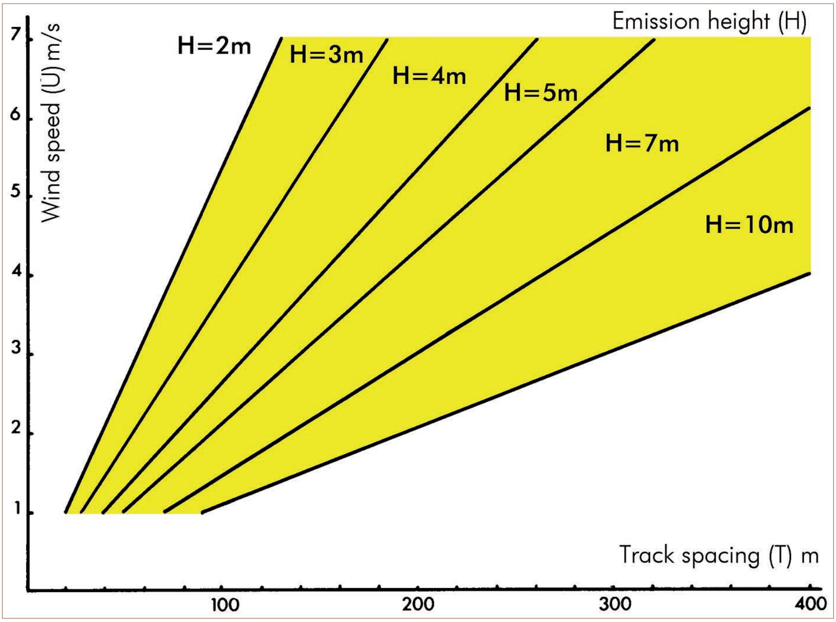


Figure 95. Maximal track spacing against vs wind speed and emission height for spraying with vehicle-mounted sprayer.

Treatment procedure

General principles

Before starting to spray, the target should be clearly defined (size, mobility, harmfulness, vulnerability) and the basic parameters determined.

Acceleration should not be modified during spraying for all the sprayer mentioned above, except for the L15 of Curtis Dyna-Fog, thanks to its radar system. The position of the gear should not be modified unless one or more other basic parameters are modified (output or track spacing).

Write down the distance covered during spray runs so that the overall treated area could be calculated.

The most suitable direction of spray runs is perpendicular to wind direction. But actually wind direction often varies after spray run orientation has been chosen. Field topography may also impose another angle. However the final result will remain satisfactory as long as the angle is not less than 25 degrees. While being relatively fixed with regards to the wind direction, track spacing shape may vary with marching hopper bands.

6. How to determine forward speed

***First of all: convert the duration into seconds**. To accomplish this, multiply the number of minutes by 60 and add the result to the number of remaining seconds.*

Example: three vehicles covered 500 m respectively in 6 min and 46 s; 4 min and 15 s; 2 min and 48 s. The conversion is as follows:

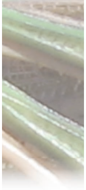
6 min 46 s = (6 x 60) + 46 = 406 seconds
4 min 15 s = (4 x 60) + 15 = 255 seconds
2 min 48 s = (2 x 60) + 48 = 168 seconds

Then calculate the forward speed in km/h.
Use the following formula: ***S = D x 3600 / T***
where: ***S*** *= forward speed in km/h*
D *= distance covered in km*
T *= time to cover this distance*

Calculation related to the above data:
1st vehicle: *S = 0.5 x 3600 / 406 = 4.53 km/h*
2nd vehicle: *S = 0.5 x 3600 / 255 = 7.06 km/h*
3rd vehicle: *S = 0.5 x 3600 / 168 = 10.71 km/h*

Spraying

- Start spraying heading the course by the help of a compass.
- Stop spraying at the end of spray run (which is easy when using electrical sprayers).
- With the help of the compass, turn 90 ° upwind.
- Run upwind over the track spacing distance, with the help of the vehicle tachymeter.
- Turn 90 ° so that the vehicle direction is parallel to the preceding spray run.
- Start again spraying until the end of the spray run. Repeat the operation until the whole field is treated.



Emission height H (m)	Wind speed U (m/s)	Droplet size (microns)								Maximal track spacing T (m)
		40	50	60	70	80	90	100	120	
2	1	42	27	19	14	11	9	7	5	20
	2	85	54	38	28	22	17	14	11	40
	3	127	82	57	42	33	26	22	17	55
	4	170	110	76	56	44	35	28	22	75
	5	213	137	95	71	55	44	34	28	90
	6	255	164	114	85	66	53	43	34	110
	7	298	199	133	100	76	61	50	39	130
3	1	64	41	29	21	16	13	11	9	28
	2	127	82	57	43	33	26	22	17	55
	3	191	123	86	64	49	39	33	25	80
	4	255	164	114	84	66	52	43	34	110
	5	320	205	145	106	82	66	54	42	140
	6	384	246	174	128	98	79	65	51	165
	7	448	287	203	149	115	92	76	59	200
4	1	85	54	38	28	22	17	14	11	40
	2	170	110	76	56	44	35	28	22	75
	3	255	164	114	85	66	53	43	34	110
	4	340	219	152	113	87	70	58	45	145
	5	426	274	190	149	109	88	72	56	180
	6	510	329	229	170	131	105	86	68	220
	7	596	384	266	200	152	122	100	78	260
5	1	106	68	48	35	27	22	18	14	45
	2	213	137	95	71	55	44	34	28	90
	3	319	205	145	106	82	66	54	42	140
	4	426	274	190	149	109	88	72	56	185
	5	532	342	238	177	137	110	90	70	230
	6	638	411	286	213	164	132	108	85	275
	7	745	479	333	248	191	154	126	99	320
7	1	149	96	67	55	38	31	25	20	65
	2	298	192	133	99	77	61	50	39	130
	3	448	287	203	149	115	92	76	59	195
	4	596	384	266	200	152	122	100	78	260
	5	745	479	333	248	191	154	126	99	320
	6	894	575	400	298	230	184	151	118	390
	7	1042	671	467	348	268	215	176	138	400
10	1	213	137	95	71	55	44	34	28	90
	2	426	274	190	149	109	88	72	56	185
	3	638	411	286	213	164	132	108	85	275
	4	851	548	381	284	224	175	144	113	370
	5	1064	685	485	355	273	219	180	141	400
	6	1277	822	571	426	328	263	216	169	400
	7	1489	958	667	496	383	307	251	197	400

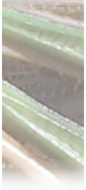
Table XXXV. Drift of droplets and maximal track spacing to be adopted when spraying with vehicle-mounted sprayers.

Gear lever position	Vehicle speed (km/h)	Track spacing					
		50 m		75 m		100 m	
		Liquid nozzle (mm)					
		2.5	3	2.5	3	2.5	3
1st + reduction	4.77	2.04	2.30	1.53	1.72	1.02	1.15
2nd + reduction	7.91	1.24	1.36	0.93	1.02	0.62	0.68
1st normal	10.81	0.91	1.01	0.60	0.75	0.45	0.50

Table XXXVI. Abacus for the use of Land Rover 110 diesel equipped with exhaust nozzle sprayer (Rachadi, 1989). Volume (litres) of technical Malathion applied per hectare.

Gear lever position	Vehicle speed (km/h)	Track spacing					
		50 m		75 m		100 m	
		Liquid nozzle (mm)					
		2.5	3	2.5	3	2.5	3
1st + reduction	4.70	2.06	2.25	1.54	1.72	1.03	1.15
2nd + reduction	7.12	1.38	1.54	1.03	1.15	0.69	0.77
1st normal	10.81	1.30	1.46	0.97	1.09	0.65	0.73
3rd + reduction	11.32	0.86	0.98	0.65	0.74	0.43	0.49

Table XXXVII. Abacus for the use of Mitsubishi L200 diesel equipped with exhaust nozzle sprayer (Rachadi, 1989). Volume (litres) of technical Malathion applied per hectare.



Gear lever position	Vehicle speed (km/h)	Track spacing					
		50 m		75 m		100 m	
		Liquid nozzle (mm)					
		2.5	**3**	**2.5**	**3**	**2.5**	**3**
1st + reduction	7.82	1.24	1.40	0.93	1.05	0.62	0.70
2nd + reduction	13.53	0.72	0.80	0.54	0.60	0.36	0.40

Table XXXVIII. Abacus for the use of Toyota Land Cruiser gasoline equipped with exhaust nozzle sprayer (Rachadi, 1989). Volume (litres) of technical Malathion applied per hectare.

Gear lever position	Vehicle speed (km/h)	Track spacing					
		50 m		75 m		100 m	
		Liquid nozzle (mm)					
		2.5	**3**	**2.5**	**3**	**2.5**	**3**
1st + reduction	3.53	2.76	3.08	2.08	2.31	1.38	1.54
2nd + reduction	6.45	1.52	1.70	1.14	1.27	0.76	0.85
1st normal	6.86	1.42	1.60	1.06	1.20	0.71	0.80
3rd + reduction	11.80	0.82	0.94	0.61	0.70	0.41	0.47
2nd normal	12.63	0.78	0.86	0.58	0.64	0.39	0.43

Table XXXIX. Abacus for the use of Toyota Land Cruiser diesel equipped with exhaust nozzle sprayer (Rachadi, 1989). Volume (litres) of technical Malathion applied per hectare.

Treatments with aerial equipment

Flow rate calibration

Basically, aerial application should not be performed without scrupulous flow rate calibration. Considering the low volumes involved and the highly concentrated formulations used in acridid control, calibration mistakes may have negative effects on the efficacy and the environment. The consequences may also be costly to the affected countries and to the international community of donors.

For the same reason, calibrations of ULV formulations should be performed with a neutral liquid having the same viscosity as the formulation.

Aircrafts equipped with electric or hydraulic pumps can be adjusted on the ground. In this case, calibration may be made directly by using the formulation itself provided the liquid is collected. When the aircraft is equipped with a propeller pump, calibration is made in flight.

Determination

A paragraph was already devoted to calculations of basic parameters and calibrations (see § Determining track spacing, p. 115). The approach is the same for the calculation of aircraft flow rate. The output of each atomiser is obtained by dividing the global flow rate by the number of atomisers set in action.

7. Example of flow rate calculation for aircrafts

1st example:
What would be the output of each nozzle of an aircraft spray boom equipped with 32 spray nozzles, considering that the volume of application is 12 l/ha, a flying speed of 160 km/h and 25 m track spacing.

By using the formula:

$$S = 160 \times 25 \times 12 / 600 \times 32 = 2.5 \text{ l/min per nozzle}$$

2nd example:
Calculate the output of each atomiser of a Cessna Ag Truck flying at 166 km/h equipped with 6 atomisers, considering that the volume of application is 1 l/ha and the track spacing 110 m.

$$S = 166 \times 110 \times 1 / 600 \times 6 = 5.07 \text{ l/min per atomiser}$$

Application to MICRONAIR atomisers:
Starting from the 2nd example, determine the working pressure and the VRU sets for AU4000 atomisers.

Thus the formula for calculating the output of aircraft is:

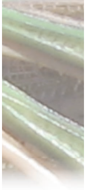
$$\mathbf{F = S \times T \times V / 600 \times n}$$

where “n” represents the number of spray heads (atomisers of nozzles).

In flight calibration (after Castel, 1986)

When the aircraft is equipped with a propeller driven pump and when there is no electronic flow regulator, the flow rate calibration must be performed on flight. The following procedure can be used:

- Put 10 to 15 litres of ULV liquid (or 60 to 80 litres of water) in the tank.
- Set the flow regulator (VRU) or place the orifice plate corresponding to the required output, following the manufacturer’s indications.
- Takeoff, adopt the emission height and the flying speed for spraying; start spraying and maintain the chosen working pressure.
- Spray until the needle of the manometer starts to fall down, then immediately switch off the flow valve. Now all the whole spraying system is full of product.
- Land, then refill the quantity of liquid for spraying during one, two or three minutes. **For ULV applications, the flow obtained with preliminary water tests, should be raised 1.2 time.**
- Fly again, spray while recording the time from the starting of the spray until the needle (of the manometer) begins to fall down. Close the flow valve and land.



- Make the necessary adjustments by varying the pressure, the distance or the orifice plates of the nozzles.
- Put into the tank the exact quantity of formulation for a one or two minute spray, then execute a final check spray flight over the target zone while recording the time.
- After landing, if required, make a last adjustment of the pressure.

Ground calibration

- Pour 10 to 15 litres of the formulation (or a liquid having the same viscosity) into the tank.
- Set the VRU at the required output.
- Start the aircraft engine and the spray pump so that the spraying system is under pressure.
- Place a clean bucket underneath each spray head, then open the flow valve and let the liquid to pour out until the air is flushed from the system.
- Close the flow valve. Pour back the collected liquid into the tank and place again the buckets underneath the spray heads.
- Collect the spray liquid over one or two minutes and then close the flow valve.
- Measure the liquid collected from each spray head and compare with the expected output. Adjust the pressure accordingly or choose another orifice.
- When the correct orifice and right pressure are found, a final fly test is useful and might be followed by a last adjustment of pressure.

Determining track spacing

For the sake of cost optimisation, the widest track spacing will be preferred as long a correct spray is possible. Actually, it is a matter of finding a compromise between the requirements of acridid control (quick intervention together with maximal efficacy) and the following constraints:

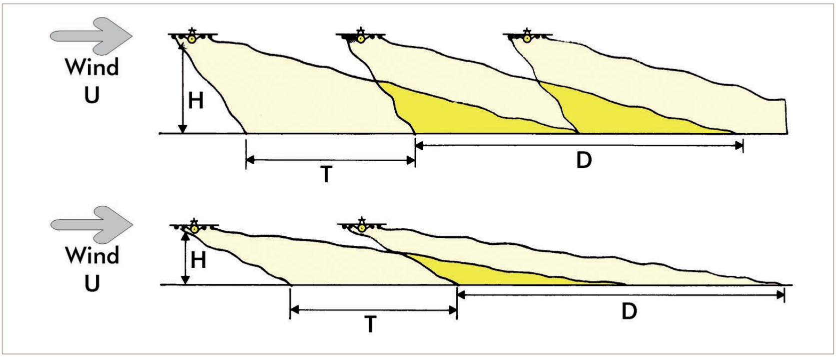
- **Plant cover:** With high and thick vegetation tracks spacing should not be wide.
- **Type of formulation:** Water-based formulations does not suit ULV technique. Large droplets are required so that they may rapidly impact the vegetation. They cannot bear important drift because of high evaporation risk.
- **The insecticide mode of action:** When using short knockdown short persistence insecticides, track spacing must be narrower and vice-versa.
- **The wind speed/emission height combination** must be taken into account (tab. XL).

Depending on the insecticide and the type of biological target, track spacing between 100 and 400 metres are adopted for blanket coverage, 400 to 1,000 for irregular coverage and 1,000 to 2,000 for barrier. In most cases of blanket coverage, track spacing varies from 100 to 150 metres.

Essentially, the basic principle is to make sure that the swaths overlap for blanket application (fig. 96).

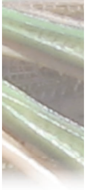
Emission height H (m)	Wind speed U (m/s)	Droplet size (microns)								Maximal track spacing T (m)
		40	50	60	70	80	90	100	120	
5	1	106	68	48	35	27	22	18	14	46
	2	213	137	94	70	54	44	38	24	90
	3	319	205	143	106	82	66	54	42	140
	4	426	274	188	140	109	88	72	56	180
	5	532	411	238	177	136	110	90	70	220
	6	638	432	286	212	164	132	108	84	270
10	1	213	137	95	71	54	43	35	28	90
	2	426	274	188	140	109	88	72	56	180
	3	638	411	286	212	164	132	108	84	220
	4	851	548	381	283	218	175	143	112	370
	5	1064	685	476	355	273	219	179	140	400
	6	1277	822	571	425	328	263	216	169	400
15	1	213	137	143	106	82	66	54	42	200
	2	638	411	286	212	164	132	108	84	270
	3	937	616	428	319	246	197	161	126	400
	4	1277	822	571	426	328	263	216	169	400
	5	1595	1027	714	532	410	328	269	211	400
	6	1915	1233	857	638	492	395	324	254	400
20	1	426	274	190	142	109	87	72	56	180
	2	851	584	381	283	219	175	144	113	350
	3	1277	822	571	425	328	263	216	169	400
	4	1702	1096	762	567	437	351	288	225	400
30	1	638	411	286	213	164	132	108	84	220
	2	1277	822	571	426	328	263	216	169	400
	3	1915	1233	857	638	492	395	324	254	400
40	1	851	548	286	213	164	132	108	84	400
	2	1702	1096	571	426	328	263	216	169	400

Table XL. Drift of droplets and track spacing to be adopted for blanket spraying in aerial applications of acridids.



D: droplet drift (swath width), H: emission height; T: track spacing.

Figure 96. Adjustment of emission height according to wind speed (after Ciba Agrochemicals, 1969). H x U should remain constant. When the wind speed doubles, the emission height must be lowered by half.



Determining emission height

The following factors determine the emission height:

- **Wind speed** (see § "ULV formulations", p. 34).
- **Aircraft specifications**: aircrafts designed for plant protection applications can easily fly at very low altitude but heavy load aircraft can fly only at relatively high altitudes which makes them unsuited for locust control in hot zones.
- **Droplet spectrum:** large droplets require a higher emission point.
- **Volatility of droplets:** droplets of water-based formulation have a high evaporation index. They should not stay suspended in the air for long. Droplets must be released just above the vegetation.

Some of these factors may vary from a flight to another and sometime during the same flight. Let us remember the relationship between emission height (**H**), drift distance (**D**) wind speed (**U**) and sedimentation velocity (**Vs**) of droplets (see p. 31-32):

$$\mathbf{D = H \times U / Vs}$$

H x U is a theoretical constant with which the emission height can be estimated. In practice one can consider that the maximum emission height is reached when the swath width is a little wider than that expected.

If the flight is too low there is a strip effect with under dosed zones. If the flight is too high there is an excessive drift which entail droplet deposit beyond the target zone. For a given constant (H x U), it is recommended to adapt track spacing so that it remains within the optimisation limits (tab. XL).

8. Example of emission height calculation

Determine the emission height, which ensure 180 m track spacing, for a blanket spray with a wind speed of 4 m/s:

> *Table XL shows that for a wind speed of 4 m/s, 5 m is high enough since the column T shows 180 as a possible track spacing.*

Determine the emission height which ensure 150 m track spacing, for a blanket spray with a wind speed of 2 m/s:

> *10 m is correct because with a wind of 2 s/s a track spacing of 150 m is possible.*

In most cases of acridid control, the emission height varies from 5 to 20 m above the vegetation, for a wind speed between 1 and 6 m/s. The highest levels are adopted for widest track spacing like those recommended with fipronil.

Recapitulation of application parameters

Volume of application per hectare
It is pre-determined by the dose of application and the formulation content.

Flying speed
It depends on the aircraft specifications. For a given aircraft it seldom varies (tab. XXIV and XXV).

Track spacing and emission height
These two parameters are interdependent. To determine them, see table XL.

Global output
It depends on the volume of application, the flying speed and the track spacing. The global output can be calculated by using the following formula:

$$F = S \times T \times V / 600$$

The output of each spray head
It equals to the global output (**F**), divided by the number (**n**) of spray heads:

$$\text{output of each spray head} = F / n$$

Micronair settings: refer to table XXVI and, according to the model choose the orifice (of the VRU) and the corresponding pressure. If necessary change the orifice plate of the VRU.

Calibration of droplet size
Refer to droplet size graph. Diagram shows droplet size versus rotational speed. Refer to the tables showing the setting of fan blades (fig. 73).

Spraying

First, the pilot flies over the site and lines up towards two flags at each side of the target zone. Then he descends to the spaying height for the first pass and starts the spray just above the first flag. He flies a series of passes, gradually moving upwind across the target zone (fig. 97). At the end of each pass the pilot has to complete a procedure turn. Initially, as he approaches the end of a pass, he increases the power, shut off the spray, pull up sharply to above 15 m, turns away about 45 ° and then brings the aircraft to approach the next swath. The power required depends on the load and height of obstacles but adequate speed and power are essential to guard against stalls or incipient spins. Sometimes it is possible to fly a “race track” pattern (fig. 98) which allows a wider turn but necessitates additional flag men, which is not always available in remote and desert areas. The race track pattern can give a more even spray coverage, as the aircraft is flying successive passes in the same direction. When obstructions are close to the edge of the field, the pilot will normally fly one or two passes along the edge and along each headland to “finish off” after completing the main part of the field (Matthews, 1979).

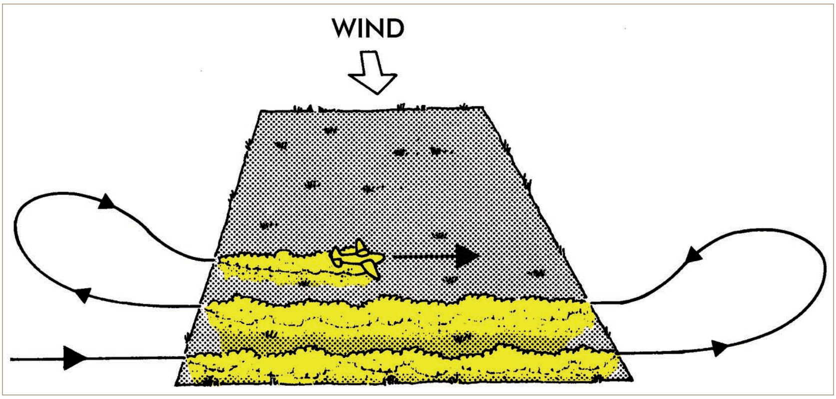


Figure 97. Schematic representation of U-turn flight tracks (after Matthews, 1985).

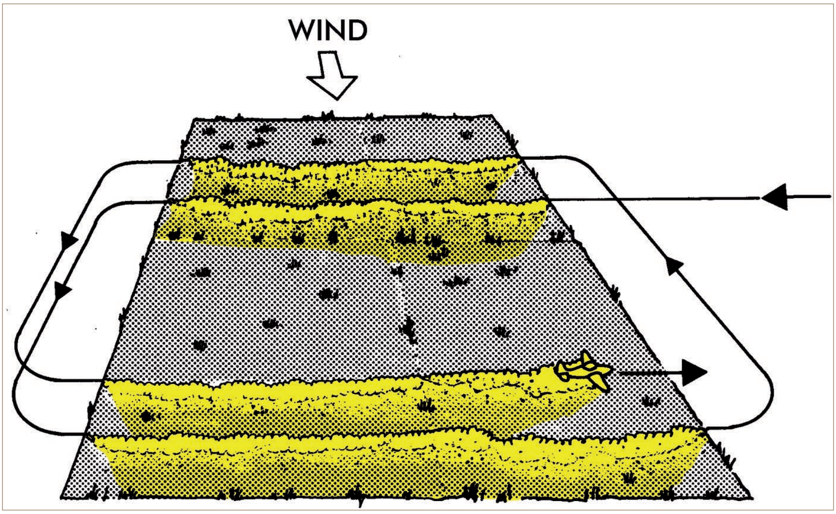


Figure 98. Round robin system of spraying (after Matthews, 1985).

Inspection and optimization of control operations

GPS and spray monitoring technologies

Satellite constellation

Global Positioning System (GPS) is a satellite based global positioning navigation system created and operated by the US Department of Defense. Originally intended

solely to enhance military defence capabilities, GPS have expanded to provide highly accurate position and timing information for many civilian application.

The basic GPS is defined as the constellation of 24 satellites in six orbital circle paths which circle the earth twice each day at an inclination angle of approximately 55 degrees to the equator. The satellites are travelling at a speed of about 12,000 km/h, which allows them to circle the earth once every 12 hours. They are powered by solar energy and are built of last about 10 years. If the solar energy fails (eclipse, for example), they have backup batteries on board to keep them running. They also have small rocket booster to keep them flying in the correct path.

This constellation of satellites continuously transmits coded positional and timing information at high frequencies. One of the frequencies is devoted to the civilian receivers. The signals travel a "line of sight", meaning it will pass through clouds, glass and plastic but not go through most solid object such as buildings and mountains. GPS receivers with antennas located in a position to clearly view the satellites, pick up these signals and use the coded information to calculate a position in earth coordinate system.

When introduced in 1993 the GPS standards available to civilian users, incorporated a deliberate degradation of the system's accuracy using a technique known as "Selective Availability". Horizontal positional accuracies of 100 m became available. On 1st May 2000, the US Department of Defense discontinued the use of selective availability, rending possible a much higher degree of accuracy. Thus the new horizontal accuracy standards are based on signal space errors and state a global average error of less than 13 metres.

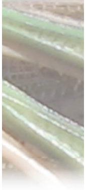
Differential GPS (DGPS) removes this induced error as well as errors caused by ionospherical interference. It also removes multipath errors caused by the satellite signals that bounce off terrain features before reaching the GPS receiver. DGPS positioning data can be accurate to within a metre or less.

GPS guidance technology systems become necessary in acridid control. They allow the control team to delineate spray plots by integrating, if possible, Geographical Information System (GIS) positional information into the aircraft system. They give the pilot the ability to navigate directly from the airstrip to the plot and back. They give the pilot guidance in aligning each spray path across the plot and provide a record of the area that was sprayed. These records can be viewed on the GPS system screen in the cockpit for immediate correction or can be downloaded to a computer. The downloaded spray records can be achieved and later imported into a GIS system for analysis with spray deposition models.

Receiver technology

Receivers are parallel multi-channel design. They have between 5 and 12 receiver circuits, each devoted to one particular satellite signal. So, strong locks can be maintained on all the satellites all the time. Parallel channel receivers are quick to lock onto satellites when first turned on and they are unequalled in their ability to receive the satellite signal even in difficult conditions.

Receivers have been miniaturized to just a few integrated circuits and so are becoming very economical. That make the technology very accessible and GPS navigation is becoming more common.



GPS is the only system of the kind available for civilian uses but not for long. Within a few years, **Galileo**, an European system will complete and compete with the American GPS system to form the **GNSS: Global Navigation Satellite System**. With Galileo, the availability of two or more constellations, more than doubling the total number of available satellites in the sky will enhance the quality of the services, thus increasing the number of potential users and applications.

The existence of two independent systems is a benefit to all users since they will be able to use the same receiver to pick up both GPS and Galileo systems. The GNSS system (Galileo + GPS) will allow development of algorithms which can lead to **centimetre accuracy** most of the time.

Choosing receivers

The price is of course an important factor. However down-market receivers should be avoided, as they may have important limitations. Sometimes the necessary accessories are very expensive. The possibility of connection with a computer and the availability of out antenna should be carefully considered. Do not neglect the display size, the simplicity of use and the possibility of being connected to the vehicle batteries.

Benefits of GPS technology

GPS technology has made a great improvement in acridid control applications. Therefore this equipment should required whenever possible in all aerial or ground application. The benefits to be drawn from GPS technology includes precise delimitation of target zones and accurate guidance of spray tracks.

Delimitation of target zones

GPS can offer significant time saving by reducing set up time at survey site. It also provides accuracy down to less than 10 metres which is sufficient for a good delimitation of target areas. This is particularly useful when an infested area contains excluded zones such as villages or ponds. This possibility is a great advantage since it implies reducing the quantity of pesticide use while preserving the environment.

A typical GPS installation in an aerial application aircraft consists of a moving map display, key pad mounted on the cockpit instrument panel and a light bar mounted at the very top of the panel or outside of the cockpit on the nose of the aircraft. The light bar should be in the pilot’s direct field of vision, when looking forward from the cockpit. A series of lights on the bar help align the aircraft properly along the swath. In some systems the light bar displays other informations such as whether the spray is on or off. Before scheduling the spray operations, the team leader and the pilot must locate the coordinates of a series of points delineating the boundaries of the area to be spayed. This can be done by the ground team by hand-held GPS receiver. When this series of points is loaded into the GPS receiver of the aircraft, it will form a polygon which represents the spray plot. The team leader must also locate any excluded areas such as ponds, rivers, villages, etc.

The GPS receiver of the aircraft will give the pilot the heading position to the spray area polygon. When the aircraft has reached that point, the pilot may, if possible,

let the guidance system software choose the swath or one leg of the polygon can be flown in the desired direction, according to the wind direction.

When the insecticide in the tank has been used, the GPS unit will record the shut off point and the system will give the direction back to the ait strip where the aircraft was loaded. After the aircraft has been reloaded, the GPS receiver will direct the pilot again to the spray plot and set up a swath which will start at the point where the previous spray ended, so no gap is left.

The ability of GPS to accurately align each swath, helps to ensure uniform application throughout the designated spray plot. The system can record the spray aircraft's path, cross track error, the exact flow rate and whether the product is being applied. The flow rate information can be imported from a compatible flow monitoring system.

It is preferable that the GPS unit include a screen in the cockpit which displays a moving map showing the outline of the spray block and the continuous path of the aircraft above it. These data enable the pilot to make immediate correction. After finishing the last swath over the block, the pilot can climb to a safe altitude and carefully scrutinize the screen displays for possible gaps between swath runs or other indications of unsprayed areas, which can be sprayed before leaving.

After returning into the airstrip the pilot transfers the information stored in the aircraft's GPS unit, to a computer diskette or other storage media. The storage devices can transfer the information to a PC. The aircraft's path over the spray plot can be displayed to the ground team. They can determine whether the spray block has received the full coverage. If the team leader decides is needed, it can be made immediately while the aircraft is still available.

Accurate guidance of spray runs

Track guidance system provided by GPS technology is of high importance in the improvement of track spacing accuracy, without using land marks. It is possible to precisely run or fly without significant deviation from the pre-determined spray runs. Hence there is no need for field marking.

The mobile GPS receiver may be used as a very efficient for vehicle guidance while treating (fig. 99 and 100). Thus it is possible to spray according to parallel runs visualised on the GPS receiver display. It is also possible to drive round, obstacles such as dunes, bushes, hillocks or hills and again step into the current track line. When the hectometric speedometer of the vehicle is working well, it is possible to do without flag people.

When GPS traces together and corresponding way points, it is possible to accurately calculate the treated area and, hence, the exact dose of a.i. per ha.

The benefit of GPS is even greater when it is integrated with a spray monitoring system linked to the vehicle speed (radar).

Inspection of treatments

The object of acridid control operations is to control acridid populations by reducing their numbers. This object (acceptable acridid mortality) may be hindered by many uncontrolled factors, such as technical drawbacks, un-correct calibrations, logistic failures etc. Being completely certain that calibrations have been correctly

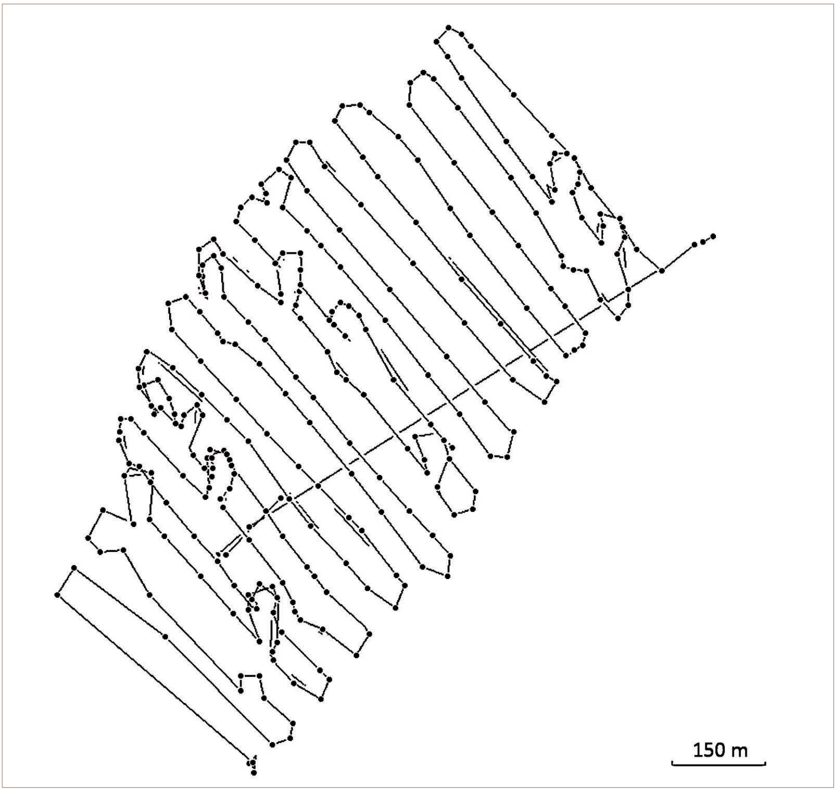


Figure 99. Layout of a pyrethroid spray. The trace irregularities are due to sand dunes that cross the spray tracks during which the spray was interrupted.

done and a good chemical was applied at the right dose, is not sufficient. **It is only the actual biological effect, noticed on the field, which is valid.**

Inspections of effectiveness are essential because of economic and environmental requirements. Any treatment which does not attain its target means pollution and obligation of treating again sometimes over a wide area. Furthermore, this entails a high risk for the situation to be beyond any control. It is absurd to treat tens of thousand hectares and notice afterwards that the product was not effective or the dose was not sufficient. Errors can be admitted in such complex operations but is not acceptable to neglect being provided with the means to be able to detect and overcome them before the consequences become irremediable.

Therefore, it is very import to include efficacy inspections within the control strategy and provide control teams with the means to enable them to check the quality of sprays.

During large scale interventions, it is not necessary to undertake precise checking operations after each spray. However, detecting low efficacy as soon as it occurs necessitates taking preventive measures and undertaking inspections during control operations.

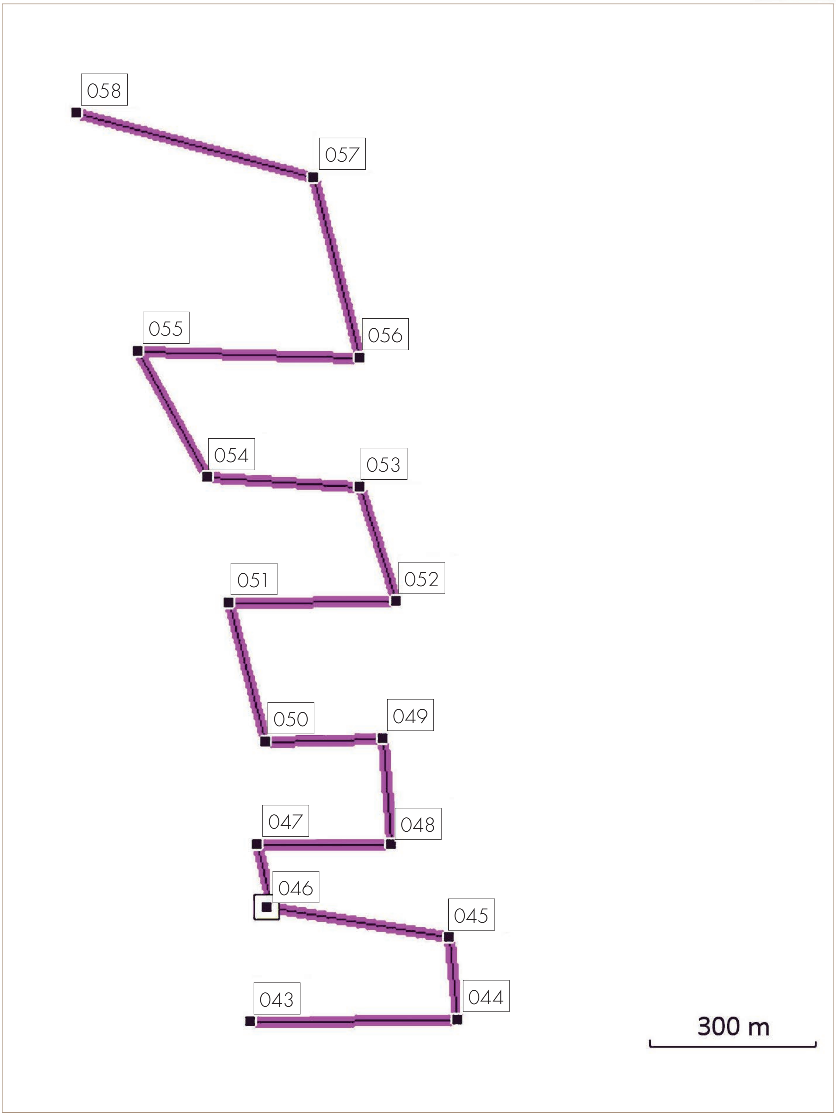
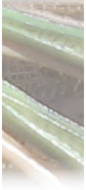


Figure 100. GPS tracks of a barrier treatment demonstration in Guzor region, Uzbekistan. The area was very sloping and undulating.

Preventive measures

The first measure is to meticulously perform the basic calibrations. Then checking spray quality should be executed consecutively to the basic calibrations, before starting any treatment. It is mainly a matter of visual estimations of density and droplet size as well as swath width.



Post-treatment inspections

The most desirable is to undertake routine checks of the efficacy after each treatment. During small-scale aerial operations, inspections may be undertaken by ground teams, meanwhile during large-scale operations, these tasks, as well as flagging, are entrusted to helicopter teams.

Routine inspections

Establishing routine inspections enables control teams to detect weaknesses as soon as they occur. **Thus, as soon as a treatment appears non efficient, samples can be taken to estimate the spray quality before suspecting the chemical.**
Among the causes of inefficacy:

- Incorrect calibration of one or more basic parameters. Checking basic parameters makes it possible to identify the cause of the default.
- If atmospheric conditions are the cause of the default, treatments should be postponed until improvement of the weather conditions.
- It is only when the accuracy of all calibrations is verified, the atmospheric conditions are fully suitable and the acridids are really attained by droplets that the chemical could be questioned. In this case, immediately stop spraying and report to the hierarchy. Meanwhile, if possible resume the operations with an alternative recommended chemical.

Optimising factors of ground operations

Acridid control consists of accomplishing different interdependent tasks, starting from signalling infestations to post treatment inspections. Any factor which interrupts the correct course of a task, might have a negative effect on the final result, i.e. the control of acridid infestations. The fact that aerial operations depend on the ground team support, emphasize the importance of optimising those factors, at all the chain levels.
The correct use of ground means depends on the human and material factors.

Intervention equipment

Facts

In Sahelian-Saharan zones, particularly during rainy seasons, ground displacement are very difficult and vehicles are often roughly handled. There are frequent breakdowns, sometimes final. The frequency of breakdowns depend on the equipment robustness but the span of immobilization varies with the availability of spare parts, the skill of the team and the scale of damage.

The working of ground equipment is mainly linked to the state of the vehicles. Equipment depends on the vehicle limits and weakness. Thus, forward speed varies within 5 to 15 km/h (as maximum) and the emission height varies from 2 to 10 metres. Besides, qualitative performance of the vehicles has a great influence on the accuracy of sprays. Thereby, improvement of the former enhances the latter. For instance, a work accomplished by a vehicle equipped with a tachymeter and a hand accelerator is much more accurate. Unfortunately, so far almost all the vehicles used in acridid control are not equipped with these very useful devices. Many brands and models of all terrain vehicles have been recently used to carry

sprayers. They are mainly Land Rover, gasoline and diesel; Toyota Land Cruiser, gasoline and diesel; Mitsubishi Pajero, gasoline and diesel; Mercedes Unimog and several other types of trucks.

This great heterogeneity of brands and types inevitably entails an increase of breakdowns and a great variation of quantitative and qualitative performances. A given gear position does not correspond to the same forward speed with every all-terrain vehicle, whereas many operators shift from one vehicle to another and engage the same gear position, thinking that they work according to unchanged parameters.

Improvements

It is possible to alleviate the above disadvantages by giving more technical consideration to the purchase of equipment:

- **Selecting vehicles and spray equipment**. Vehicles for transportation and spraying should be selected according to technical criteria, among models and types which have already been thoroughly tested in acridid control areas.
- **Homogenization of vehicles and spraying equipment**. The great diversity of, brands and models requires keeping important stock of spare parts, which is costly and difficult to manage.
- **Devices for improving spray accuracy.** It is highly advisable that vehicles, which carry sprayers, be equipped with minimum improvements such as: hand-notched accelerators, adding hectometric and a gyrating compass. Theses devices constitute an important optimization factor. Product and time saving entailed by accuracy, homogeneity and rapidity, largely offset the purchase and the installation costs.

New technologies make it possible to provide more or less sophisticated devices such as GPS and spray monitoring system.

Message transmission means

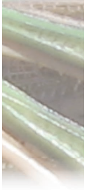
Thanks to new technologies there are significant improvements in telephone communications. However telephone via satellites is still too expensive to be used for daily transmission routines. Therefore radiotelephone remains the major means of communication between teams and the management of acridid control, at local or national levels.

For optimal use of radiotelephone, the following recommendations should be considered:

- **each team** should be provided with a radiotelephone;
- **the daily transmission routine** should be undertaken every day at fixed hours for each station;
- clear and concise messages should be transmitted according to standardised procedure. The document where messages are recorded should be the same for all teams and be clear and easy to be kept;
- **Head quarter base should permanently be tuned in**.

The human factor

Considering that acridid operation sites are very often remote and under tyring climate, particular attention should be given to the material organisation as well as to the skill of the staff.



Equipment problems

The good spirit of teams in operation should not be altered by bad preparation of the assignment. Vehicles and spray equipment should be checked before departure for the operation sites. It is of high importance to provide a minimum number of tools and spare parts. Camping equipment, particularly tents and bedding, should be chosen with care so as to provide the staff with good rest.

Skill of the staff

Each staff member, whatever may be his level or job, should accomplish his task with skill. Therefore every one should be given the relevant training corresponding to his job.

The team leader

He should be educated on acrid bio-ecology. Trained on the use of radiotelephone and on the desert navigation, with and without GPS. The team leader should master the anti-locust application techniques and post-treatment inspections. He should be well-trained on the negative effects and impacts, both on humans and the environment.

Drivers

They should have the basic knowledge on mechanics which enables them to understand the functioning of the vehicles. They should be able to fix, on the spot, the usual breakdowns. No driver should be sent for a survey or treatment assignment without being consistently trained on all-terrain driving on muddy or sandy tracks.

Labourers

Each worker should be trained to accomplish properly his task, even those considered as very simple. It is particularly vital that the insecticide handlers take usual safety measures.

Optimising factors of aerial interventions

The optimal use of aircrafts depends on two main factors. The first is of strategic nature: **infrastructure** and the other is of organizational nature: **logistics**.

Infrastructure

Each country likely to be seriously affected by acridids (locust or grasshoppers) should build a relevant number of airstrips, within a network which can be integrated into an acridid control strategy (Duranton *et al.*, 1989). This network should be composed of one main airbase, a few secondary and several backup airstrips. This infrastructure may be integrated in a global preventive system (fig. 101).

The main airbase

In most cases it could be an airport with a permanent civil activity. A permanent stock of fuel, lubricants and insecticides will be kept there, as well as spare parts for routine and statutory maintenance of aircrafts.

Secondary airbases

They are linked to the main airbase. They should be usable in all seasons, so they must tended regularly and maintained. Secondary airbases should keep additional fuel and lubricant stocks as well as all the logistics for aircraft servicing in case of the need for emergency locust outbreak control. The secondary air bases are also the offices of the preventive control teams which are the kingpin of the locust control strategy especially the Desert locust.

Temporary bases

They usually are fitted out near the villages where survey teams (within preventive control systems) are based. The airstrip usually consists of bare earth without vegetation. They are used periodically, during outbreak or plague periods, when survey and control activities are very frequent. A strategic stock of fuel and lubricant should be kept where tracks are not feasible during rainy seasons.

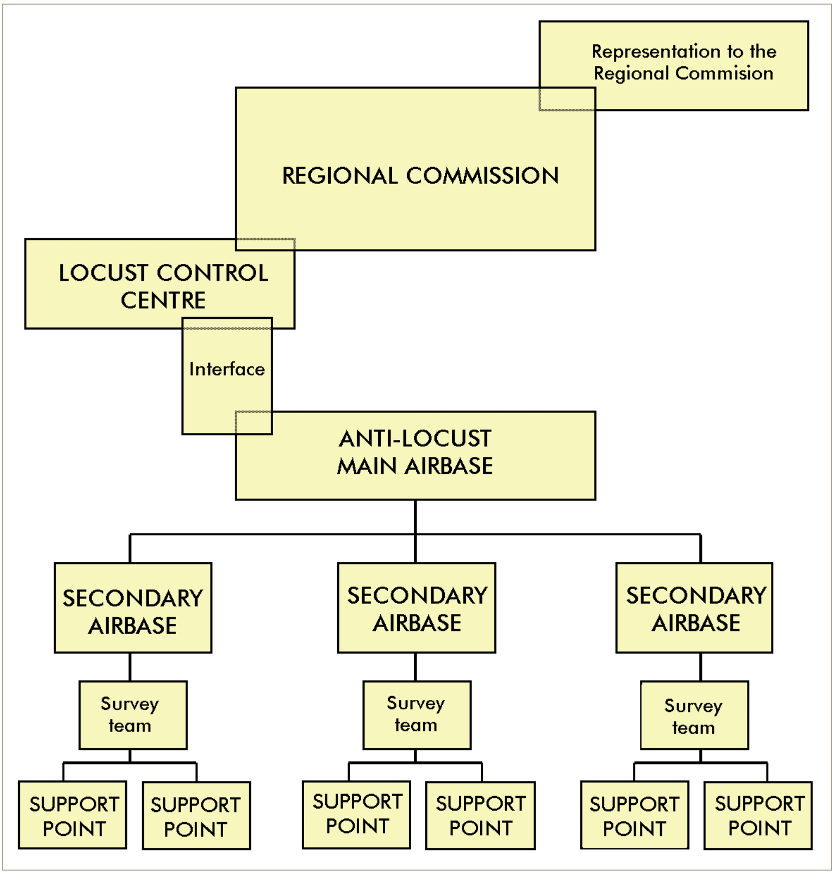
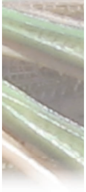


Figure 101. Diagram of Desert locust preventive control system (after Duranton *et al.*, 1989).



Ground support

Aerial operations will only be successful if ground support is sufficient. So, before starting operations, it is of high importance to make sure that all aspects of the ground support have carefully been studied. This is a prerequisite condition to guarantee the success of aerial interventions.

Therefore ground support is a fundamental factor, because it determines the success or the failure of anti-acridid operations. Any mistake in signalling or locating infestations or any default in the supply management, will result in a waste of time which can lead to suspending operations. If aerial applications are correctly organised, they may have a reasonable cost; but they rapidly become prohibitive if aircrafts are obliged to make long ferry flights or if they are often stuck on the ground for lack of foresight. In case of logistic failure, aerial means may become a hindrance to the efficacy of the whole of an anti-locust campaign.

It is the ground team leader who defines spray parameters, i.e. the volume of application, the droplet size, the track spacing and the area to be treated. The pilot is responsible for the flight security and the spray quality (Muller, 1985).

Together with the ground team, the pilot organises the lay out of treatment and the calibration of the spraying system.

It is critical that a good spirit reigns between the pilots and ground teams. Pilots have to consider the constraints which weighs on ground teams and vice-versa. Ground team have to respond to the requirements of the aircraft running. This is a *sine qua non* condition for the success of aerial operations.

Ground teams should fulfil the following tasks.

Localizing target areas

The pilot should know precisely, before each takeoff, where he should spray. He should not lose time searching for the target zone. Imprecise description of location which often results in spraying of non target areas, can now be avoided thanks to GPS. Pilots and ground teams should be provided with the same maps with a suitable scale (1/200000 or, if missing, 1/500000) for local topography.

It is sometimes useful to use landmarks to delimit areas to be treated. Sometimes, Desert locust hopper bands could be seen, thanks to their bright yellow colour, in contrast with green vegetation. However, at the end of rainy season, their colour may be confused with drying spots of vegetation already consumed (Monard-Jahiel, 1989).

Marking out and flagging

In many cases pilots can identify land marks reported on maps. But in Sahelian zones it is not wise to rely only on the position of certain villages reported on maps especially because few new maps of the Sahel are available. Many villages have disappeared or changed their location. Other villages are new and not reported on maps. In all cases GPS are now the most reliable tools for undertaking this task and **with GPS track guidance there is no more need for flagging**.

In the absence of GPS, several methods of flagging are used but none is perfect in all cases. Among the most currant:

The use of the lay of the land

The process is suitable when the target area is large enough and well delimited by tracks, reliefs, canals and rivers which could be used as markers by the pilot.

The use of flags

This method is more accurate whenever flag holders are available, especially when large areas are concerned. Flags of about 1 m are white, yellow or orange coloured. Flag holders (fig. 102) move quickly from a flight pass to the next as the aircraft progresses. They must move as soon as they see that the aircraft is flying towards them, before it flies above; then they move upwind and stop at the peg stuck beforehand, at track spacing distance (fig. 103).

The use of smoke

When waste tyres are available, it is possible to create a source of smoke that could enable the pilot to easily spot the target zone. This method is not suitable for marking spray tracks.

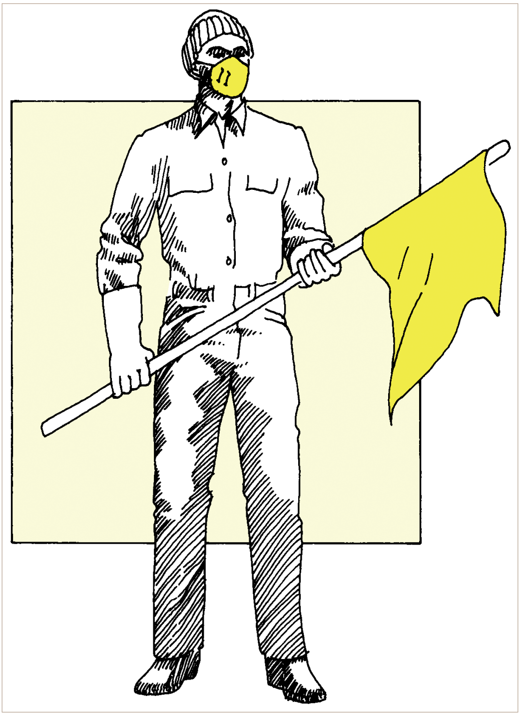


Figure 102. Flag holder wearing protective clothes (after Ciba-Geigy).

Supply

Supplying acridid control operations is often very difficult because operations almost always take place in remote zones, far from urban centres. However, difficulties should never be a justification for interrupting treatments. Running out of fuel, lubricants or insecticides may have serious consequences on the evolution of control operations.

It is recommended to provide, long before needed, strategic stocks of fuel and insecticides in areas subject to frequent outbreaks.

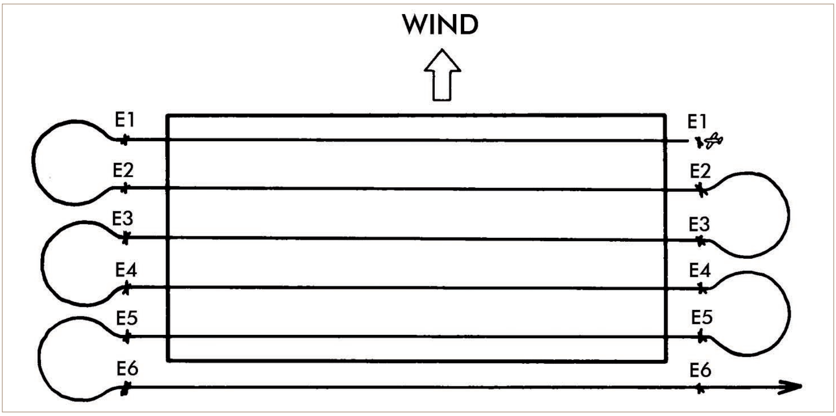


Figure 103. Successive positions of flag holders (E) (after Lancon *et al.*, 1986).

Figure 104. Insecticide handler wearing protective clothing (after Ciba-Geigy).

During control campaigns each unit should be provided by communication and transport means so that they could have the autonomy of action as large as the importance of the affected area, especially when the distance to the supply source is greater and/or the tracks are rough.

Aircraft serving

Aircraft servicing comprises several operations including fuelling, loading insecticides and daily routine maintenance. Aircraft servicing tasks require high security conscientiousness together with celerity, taking into account the strict procedure of fuelling and loading insecticides. Therefore these tasks should be performed by skilled and scrupulous people.

Requirement pertaining to fuels

- Aircraft fuel barrels should be original. They must be refused if they are not capped.
- Check for humidity as soon as the barrels are opened.
- Refuelling should be made after each landing – even in the evening – with adapted and complete tools (chamois leather, large funnel provided with a tap and a thin gauze).

Requirement pertaining to insecticides

- Operators, particularly insecticide handlers, should wear adapted, light and efficient protective clothing (fig. 104).
- Insecticide loading should be made at a flow of 400 l/min, just before takeoff. This task should be executed **with celerity but without excessive haste**.
- Formulations should be filtered. For this purpose, use appropriate tools such as a decanting tub and thin gauze at the hose tips.

Organisation and steering of a temporary acridid control air base

The location of **fuelling pit** should be conscientiously weeded so as to avoid any risk of fire. Barrels should be 10 m away from the air strip. A large foam extinguisher, maintained in perfect state and fixed on a trolley, is placed close to refuelling pit, together with a shovel and a mattock. A wind sock is also erected in the place. It allows the pilot to permanently visualise the direction and the wind force before takeoff and landing (Castel, 1982).

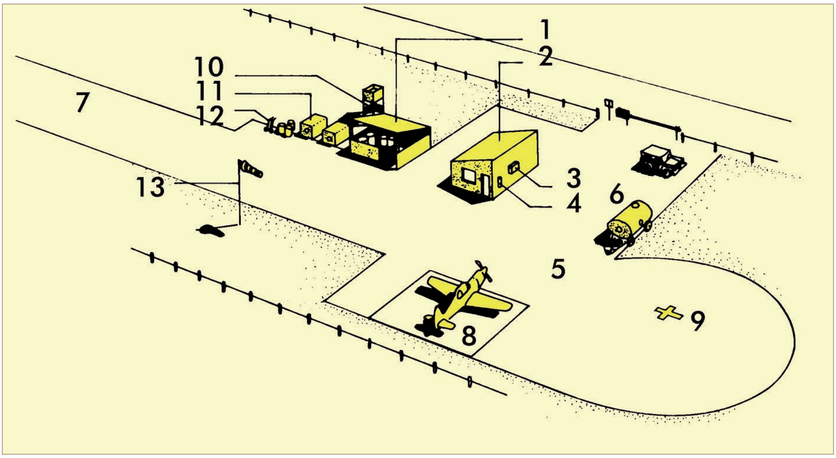
Location of the fuelling pit

A loading station is placed at each end of the air strip (fig. 105), which enables aircrafts to take off upwind whatever be its direction (aircraft should not turn with full cargo).

When the strip is less than 500 m, only one pit is set up at the end opposite to the dominant wind so that the aircraft could take off directly after having been loaded. During the rainy season in Sahelian zones, prevailing winds are West to South-West. So, the unique tip should place at the eastern, end of the strip.

Loading pumps

Distinction should be made between the fuel pump and insecticide pump. Even when a single aircraft is in operation, it is always preferable to provide two specific pumps. They should be self-primed with a capacity of 400 l/min under low pressure. A few spare -manual pumps should be provided so that it is possible to compensate any pump breakdown.



1: Shelter for fuels and lubricants
2: Insecticide storage
3: First aid cupboard
4: Extinguisher
5: Bare area for loading
6: Water tank
7: Take off and landing strip
8: Cemented area for aircraft servicing
9: Turning place
10: Shower
11: Fuel tanks and pumps
12: Rolling extinguisher
13: Air sock

Figure 105. Layout of different working posts on a temporary locust control air base (after Shell, 1983).

Maintenance

The maintenance specific to aircrafts is undertaken under the responsibility of the pilot or the aircraft engineer. When planning acridid control programs, consideration should be given to the maintenance routine. Some servicing sequences are submitted to VERITAS checking and other are to be undertaken in registered workshops which are, sometimes, situated far away from control operation fields. Even some affected countries do not have such institutions.

Equipment used in acridid control suffers from rough conditions and the rhythm of work:

- **Atmospheric and climatic conditions** are tiring for people and equipment (oppressive heat, sand storms, turbulences),
- **Highly concentrated formulations of insecticides** which are often corrosive for rubber washers, metals and paints,
- **High rhythm of working** for controlling grasshopper pullulations or locust upsurges.

Thus, the maintenance routines become essential:

- At the end of the day, no product should remain in the spraying system nor in the aircraft tank.
- The tank and the formulation circuits should be flushed and cleaned without being dismantled.
- Aircrafts should be regularly washed with soapy water, under the supervision of the pilot or the aircraft engineer.

General links

Plague locusts and grasshopper pullulations may affect large areas and territories. Aerial control teams may have to operate in remote zones where usual telephonic communications are rather rare or, even, non existent. In regards to satellite telephone, it is too expensive to equip all the operating teams. So, radio communications are necessary to ensure:

- relations with local civil and military authorities;
- in flight safety of aircrafts;
- co-ordination with other locust control units;
- relations with locust control head quarters;
- relations with central and regional Plant Protection head quarters.

Radio sessions should be scheduled for, at least once a day, at fixed hours except for emergencies. Messages should be recorded on a register kept by the head of the aerial unit.

It is the job of the head of the unit to keep permanent contact with the local authorities so that local populations are informed and take the usual protective measures when dangerous products are used. It is particularly recommended that wells and private reservoirs are sheltered and children do not stay in the open air. Livestock should not stay on pastures due to be sprayed.

Accommodation and subsistence of the staff

The tiring conditions which weigh heavy on the staff are to be taken seriously. So, the material means should be provided, whenever possible, so as to alleviate these effects.

Special attention should be given to the flying staff. Good restful conditions are necessary. Therefore, the elementary requirement for everybody should be satisfied, i.e.:

- a healthy diet, varied and sufficient, served at fixed hours;
- a minimum and decent comfort, respecting the privacy and the belief of people (spacious tents in a sufficient number);
- a regular timing;
- a collective and firm discipline and a special care for individual problems.

Management problems

Good management is an essential optimisation factor. The management scheme should be conceived so that operations are positively viewed and not considered as drudgery. The forms should be clear as well as simple. Colligated information should be exact and accurate. There are two aspects of the management:

Steering the operations

The head of the unit should be capable of taking the decisions required by the daily management of his staff, without permanently asking for support from his hierarchy. The head of the unit should be skilled enough to assume and supervise the following necessary technical tasks:

- **Calibrate spraying systems**, according to the needs of atmospheric conditions and with the collaboration of the pilot.
- **Know the physicochemical properties** of the product used and the relevant safety measures.

- **Ensure**, with the collaboration of the pilot, that **signalling operations** are undertaken correctly and according to flight regulations.
- **Ensure that supply and maintenance** operations are correctly promptly executed, while respecting safety measures.
- **Regularly check the efficacy and the spray quality**. Take immediately relevant measures in case of efficacy problem.
- **Co-ordinate and supervise** the activities of survey, signalling and the base camp.
- **Report to the hierarchy about** the progress of the operations and the locust (or grasshopper) infestations.

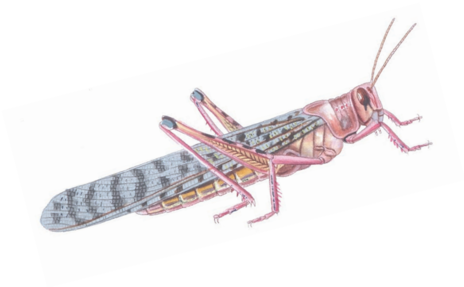
Keeping the campaign record

This document is very important and should be kept update by the head of the unit. The following items should particularly be noted down:

- **Events**, such as incidents accidents, treatment results, signalling, etc.
- **Movements of consumables** (fuels, lubricants, spare parts, chemicals, foodstuffs).
- **Detailed progress of technical operations.**

Keeping accurate records is of great importance for making a comprehensive assessment of the campaign, which enables locust operators to draw conclusions for improving the following campaigns.

Besides, the pilot keeps the ship's log in which all treatment technical data are recorded. When this book is correctly kept, it could be a valuable source of data for improving future aerial interventions and assessing the actual costs of aerial operations.



Conclusion

Curbing locust plagues demands rapid treatment of vast areas, which requires rapid responses and carefully coordinated response teams far from each other, which imposes to rapidly mobilise very important logistic means. To rise to the challenge, locust operational research has focussed on decreasing the volume of application. Hence, it is not surprising that the ULV technique was invented for the particular needs of locust control, before being adopted and developed by forestry and other fields of plant protection. This success is understandable if we consider the following:

- **The efficacy of a spray is improved** when droplet size is decreased together with the increase in the number of droplets.
- **Coverage of 20 droplets per cm²** sufficiently controls acridid infestations.
- **These findings enable considerable reduction** of volumes of application per hectare, thus decreasing the logistic costs and allowing the optimization of spray equipments.
- **Oily droplets are more effective** than water-based droplets at adhering to plant and insects, thus the efficacy per dose.
- **The simplicity and the reliability of the technique** make it possible to design simple, light and robust sprayers some of which can be used by farmers or unskilled applicators.

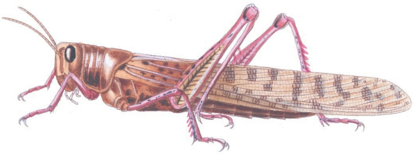
Since the invention of the ULV technique, important progress has been made in making equipment more reliable. The introduction of hand-held ULV sprayers at the farmer's level enables them to take charge of the protection of their own crops. The newly introduced vehicle-mounted electrical sprayers, are considered, by preventive control teams, as a reliable substitute for the exhaust nozzle sprayer.

The introduction of microcomputers, GPS and radar for monitoring spraying parameters is an asset for the optimal use of either aerial and ground operations. Nonetheless, these technologies will not be routinely utilised in the field unless the defects, revealed by the use in rough conditions, are corrected. Furthermore it is recommended that the manufacturers reduce, as much as possible, the number of wearing spare parts. They should also adopt a minimum harmonization, so that some basic spare parts are the same. It is particularly advisable that the electrical connexions should be of the same type.

Regarding the applications, it is of paramount importance to give great consideration to inspections of the spray quality, because many accidental and atmospheric

factors may alter operation progress. Therefore it is advisable to systematically provide control teams with the necessary tools to correctly accomplish these tasks. Automatic image analysis will only be made when thorough study is required.

Accomplishing correct sprays does not only depend on the equipment quality and its good use. The physico-chemical properties of insecticides also have determinant roles on the spray quality. The lack of standards hampers a possible harmonization of the physical specification of formulations. This make it difficult for establishing abacus which are, yet, an ideal tool for simplifying the use of spray equipment.



PHOTOS

Schistocerca gregaria (Forskål, 1758), drawings pages 44, 95, 154 and 156, after Jules Künckel d'Herculais, 1905. *Invasion des acridiens, vulgo sauterelles, en Algérie (1893-1905)*. Imprimerie administrative et commerciale Giralt, Alger. 3 Vols.

p. 5: *Calliptamus italicus*, (Linnaeus, 1758), © Antoine Foucart, Cirad.

p. 7: *Bryophyma debilis* (Karsch, 1896), © My-Hanh Luong-Skovmand, Burkina Faso, Cirad.

p. 45: Gregarious male desert locust, *Schistocerca gregaria* (Forskål, 1758), © Annie Monard, Cirad.

p. 97: Mating of migratory locusts, *Locusta migratoria* (Linné, 1758), 2006, © Michel Lecoq

p. 155: During the 1988 invasion, a swarm of *Schistocerca gregaria* flying over an island of Archipelago Cape Verde, © Maurice Balmat, FAO.

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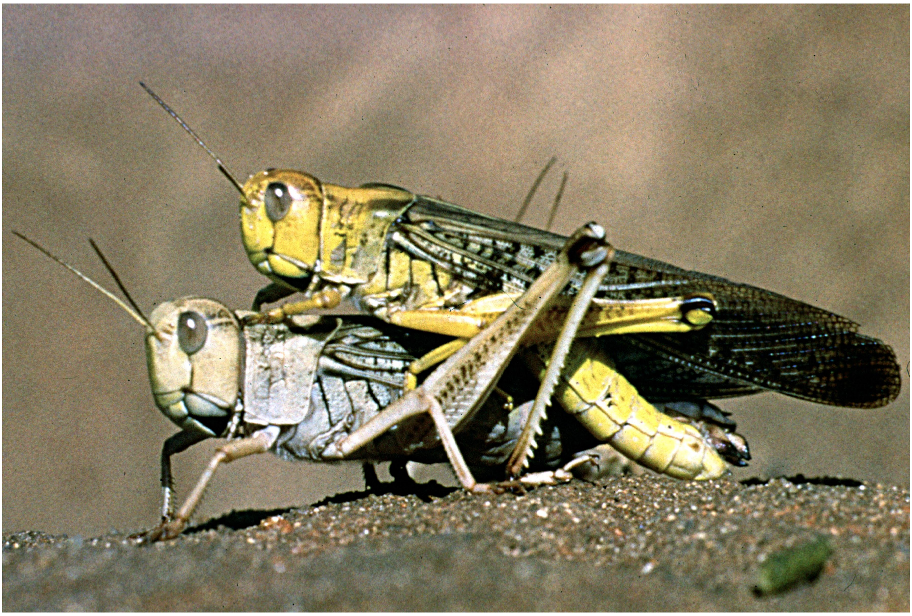

Couple of gregarious Migratory Locust, *Locusta migratoria* (Linné, 1758), in Madagascar. Note the yellow colour of the male when fully sexually mature, © J.-F. Duranton, Cirad, 1998.

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It is of paramount importance to improve application techniques when controlling locust outbreaks in developing countries. Most available documents and publications on locust control deal mainly with insecticides, rather than application techniques and the required control equipment.

The present guide book is designed to make up for this oversight. Basic principles for conducting spraying operations, descriptions of spraying equipment – especially for ultra low volume spraying – and specific locust control techniques are described in detail. The document explains how to get the most from treatments while minimizing the adverse effects to man and the environment.

This book is aimed at decision-makers and all those involved in locust control who wish to improve their knowledge of application techniques.

Tahar Rachadi is a research engineer in locust ecology and control within the BIOS Department at Cirad, Montpellier (France). Since 1986, he has been involved in popularizing ultra low volume application techniques in Madagascar and China as well as in some areas of Africa, Middle East and Central Asia.

Cover. Controlled drift spraying against Moroccan locust in Uzbekistan with a vehicle-mounted sprayer, © T. Rachadi, April 2007.

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