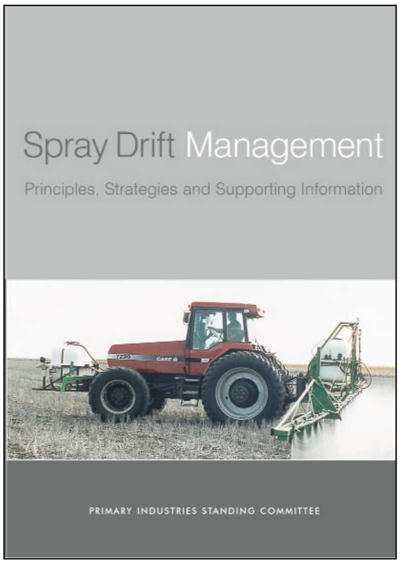
Primary Industries Standing Committee
Spray Drift Management
Principles, Strategies and Supporting Information
PISC (SCARM) Report 82



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Spray Drift Management

Principles, Strategies and Supporting Information

PRIMARY INDUSTRIES STANDING COMMITTEE

PISC (SCARM) Report 82

First published 2002 (paperback) by **CSIRO** PUBLISHING
First published on-line 2002

National Library of Australia Cataloguing-in-Publication entry

Spray drift management : principles, strategies and supporting information.

Bibliography.
ISBN 0 643 06835 X (paperback).
ISBN 0 643 06913 5 (on-line).

1. Spraying and dusting residues in agriculture. 2. Agricultural chemicals – Safety measures. 3. Pesticides – Safety measures. (Series : PISC report ; no. 82).

632.94

Available from
CSIRO PUBLISHING
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Collingwood VIC 3066
Australia

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Fax:	+61 3 9662 7555
Email:	publishing.sales@csiro.au
Web site:	www.publish.csiro.au

Set in New Baskerville 9.75 pt on 11.75 pt
Printed in Australia by Metro Printing

This project was commissioned by The Standing Committee for Agriculture and Resource Management.

In June 2001 the Australian Commonwealth and State/Territory governments created several new Ministerial Councils from the amalgamation and redirection of the work of several existing Councils.

These changes saw the winding up of the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) and the establishment of a new Council, the Primary Industries Ministerial Council (PIMC). The objective of this new Council is:

> *'to develop and promote sustainable, innovative, and profitable agriculture, fisheries/aquaculture, food and forestry industries'.*

Membership of the Council consists of the Australian Federal, State/Territory and New Zealand Ministers responsible for primary industries matters.

The Council is supported by a permanent Standing Committee, the Primary Industries Standing Committee (PISC). Membership of the Standing Committee comprises relevant Departmental Heads/CEOs of Commonwealth/State/Territory and New Zealand agencies.

Consultant

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Contents

Preface

Australian agricultural industries depend on the use of chemicals to increase their productivity and the quality of their products, which together support their competitiveness on world markets. However, there are potential risks associated with the use of agricultural chemicals. For example, the off-target movement of agricultural chemicals may affect public health, disrupt agricultural trade and impact upon the environment.

Consequently, the management of these risks in a manner that does not impact unduly on industry competitiveness is an important issue for governments, the general community and chemical users. Chemical users are defined as any landowner or occupier, spray contractor or operator, grower or enterprise manager involved in the application of an agricultural chemical. Whilst this document is directed primarily at agricultural industries, it does not exclude the use of relevant principles and strategies outlined in the document by government agencies that undertake chemical control activities.

Australia's agricultural and veterinary chemical management system seeks to ensure the safe transport, storage, handling, application and disposal of agricultural chemicals. A number of industry and government initiatives that contribute to the management of the risks associated with these activities are under way or are being implemented.

In this context, *Spray Drift Management: Principles, Strategies and Supporting Information* focuses on managing the risks associated with pesticide spray application – that is, any mechanism involving the generation, transport and deposition of liquid droplets, by which an agricultural chemical is applied to an intended target. Specifically, this document deals with spray drift, which is the airborne movement of agricultural chemicals onto a non-target area at, or shortly after, application (either by air or at ground level) with the potential for risk of injury or damage to humans, plants, animals, environment or property. It does not address the movement of agricultural chemicals to non-target areas through erosion, migration, volatility or windblown soil particles.

Although the risks related to handling agricultural chemicals is not the main focus of this document, some principles and strategies have been included for safe handling practices because of their importance in creating a safe workplace. In this respect, it should be noted that occupational health and safety requirements in relation to handling hazardous substances are established by State and Territory legislation and, therefore, may differ between jurisdictions.

In developing *Spray Drift Management: Principles, Strategies and Supporting Information,* an attempt has been made to draw together the current scientific and technical information on the causes of chemical spray drift and ways to reduce it. To date, such information has been difficult to access in a single and simple-to-understand document.

To make the document easier to use, it has been organised into two parts. The first section (Principles and Strategies) provides a set of general principles governing spray drift management as well as a number of strategies to give effect to each of the principles. These principles and strategies are based on the scientific and technical information contained in the second part of the document (Supporting Information). This part includes more detailed information that chemical users or individual primary industry sectors may use to provide a better understanding as to how the principles relate to their particular situations.

It should be stressed that *Spray Drift Management: Principles, Strategies and Supporting Information* is not intended as a code of practice for everyday use by agricultural chemical users. Rather, the document is designed to assist chemical users and/or individual primary industry sectors develop spray drift management strategies that are relevant to their particular circumstances and peculiarities. It is anticipated that, from Section 1, industry sectors will select the principles and strategies that are appropriate for their particular enterprises and tailor them into sector- or region-specific codes of practice.

Specialist consultants may be required to prepare such documents. For instance, a spray drift management strategy would need to address the specific nature of the pest problem and the climatic and geographic characteristics of the region involved. The establishment of suitable buffer zone distances and the development of a range of other spray drift management tools may also be incorporated in sector- or region-specific codes of practice.

The comprehensive nature of the scientific and technical information (Supporting Information) also makes it a useful tool for developing education and training programs aimed at increasing the skills and knowledge base of chemical users to help them make better decisions about chemical spray applications. This part of the document is a useful reference for policy makers, particularly in relation to decisions regarding regulatory versus other approaches for managing the risks associated with spray drift.

Spray Drift Management: Principles, Strategies and Supporting Information has been designed to encourage chemical users to appreciate that the application of agricultural chemicals is an activity that can affect numerous stakeholders, and, consequently, that appropriate management decisions need to be made to reduce spray drift. The sample operational plan provided (Section 3) does not seek to cover every issue involving spray drift reduction. Rather, it provides a guide to the minimum standard of planning that everyone involved in chemical application should aim to attain.

It should be noted that this document does not replace or surpass any State/Territory or Commonwealth law and chemical users should adhere to these, where applicable. In conveying principles and strategies for spray drift management that may form the basis of codes of practice, this document is not intended, of itself, to have any legal force. The information contained in this document was correct at the time of publication.

1

Principles and strategies

Introduction

The sustained production of food and fibre in Australia will depend, in the foreseeable future, on the continued use of energy and chemical inputs. The effectiveness of all chemical pesticide and fertiliser products depends upon a chemical user's ability to place the correct quantity of chemical on the intended target with the minimum loss to the environment. Consequently, application technology is a vital and important part of most crop production systems. Nearly all types of liquid pesticide application produce some off-target droplet movement. It is, therefore, vital that all chemical users are familiar with the principles of pesticide spray drift management.

The information set out in this part of the publication shows principles and strategies associated with the development of a sound spray drift management program. In the first instance, the chemical user should be involved in planning, considering land use strategies and developing awareness zones, and then, where appropriate, developing suitable buffer zones around areas to be treated with chemical sprays. The chemical user should also communicate with all stakeholders and neighbours likely to be impacted by the spray application scenario. Only when these planning and communication processes are complete should application technology be used to mitigate and reduce the potential for pesticide drift.

1.1. Property management planning

Principle

The management of spray drift should be actively considered as part of property management planning and farm or enterprise development.

Spray drift management starts when a farm or enterprise is planned or developed. Much can be done to mitigate spray drift during the planning phase of land development by identifying areas where pesticide application may conflict with adjacent land use. An essential part of spray drift management is adequate property management planning to avoid potential conflict between different land users. Farm plans must incorporate adequate spatial separation between cropped areas requiring chemical inputs and other land areas that may be affected by those chemicals (see Section 2.1. for further information).

Strategies

Preparation of a property management plan

A comprehensive property management plan should be developed prior to the planting of any crop that takes into account requirements associated with the application of agricultural chemicals.

Strategies

Development of awareness zones

- A spray drift awareness zone should be established around the field to be sprayed.
- All areas within the awareness zone that may be affected by spray drift should be identified.
- An awareness zone chart detailing susceptible areas should be produced.
- An updated awareness zone chart should be made available to the chemical user prior to any spraying operation.
- An operational plan should be prepared for all routine spraying operations that includes site-specific instructions on awareness zone location, drift reduction buffer zones and safety measures.

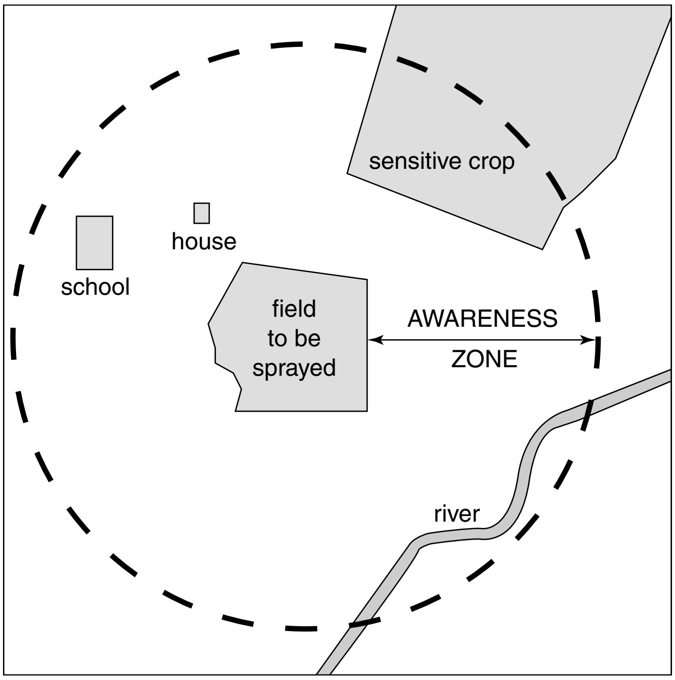


Figure 1. Awareness zone establishment and sensitive area identification.

The chemical user should be responsible for establishing a spray drift awareness zone around the property. Under most circumstances, the awareness zone for ground spraying could extend from approximately 100 m to 1 km from the paddock to be sprayed and up to 5 km from the paddock for aerial spraying. The width of the awareness zone may be extended if there are special sensitive areas nearby or the area is subject to local meteorological effects, such as cold air drainage in a valley (katabatic wind flows). Chemical users are encouraged to develop their own appropriate spray drift assessment zones. The zone should be used to aid the survey of areas or buildings outside a field to be sprayed that may be potentially sensitive to spray drift, eg. schools, dwellings, wetland areas, travelling stock routes, organic farms, etc. (Figure 1).

Important note

The establishment of a drift awareness zone at a given distance does not imply that spray droplets can or cannot be transported in air beyond that distance. The chemical user should assess the impact of spray drift on the awareness zone just prior to and for the duration of the application. The concept and use of an awareness zone should not be confused with the use and implementation of buffer zones. Before any spraying operation commences, the chemical user should survey the awareness zone for areas or buildings that may be potentially sensitive to spray drift. Some examples may be neighbouring sensitive crops, native flora and fauna, waterways and wetlands, bees, non-target plants and animals, buildings and sites of habitation. If sensitive areas are present or become established within the awareness zone, details should be recorded and, if necessary, expert advice sought.

1.2. Establishment of buffer zones

Principle

Buffer zones are useful in reducing the downwind impact of spray drift.

If it is necessary to apply agricultural chemicals when sensitive areas are downwind, buffer zones should be established on the downwind side of sprayed areas to reduce the impact of spray drift. They are usually located on the downwind side of a sprayed area and are used to protect an area susceptible to off-target spray movement. Some pesticide labels specify downwind buffer distances for specific crop/product situations – for example, the label for endosulfan use in cotton (1999/00) stated that a 200 m buffer distance was required for ground spraying. The distance required for a buffer will depend upon factors such as the type of buffer zone, weather, application method and toxicity of the chemical to the sensitive species concerned.

Strategies

In-crop buffer strips

- Chemical users should consider spraying only the upwind section of a field, such that the downwind unsprayed section is used to retain spray drift (field splitting).
- Chemical users should leave the last row or swath unsprayed on the downwind boundary of fields adjacent to a susceptible area.

Unsprayed areas should be sprayed when the wind is blowing away from the susceptible areas. This has the advantage of acting as a comparison check for the performance of the chemical. Buffer strips reduce spray drift by adsorbing particles onto the vegetation surface as the air flows over the buffer area. Subsequent follow-up sprays should take into account the possibility that the initial unsprayed area may have been subject to spray drift, which may result in chemical deposits on that area which exceed Maximum Residue Levels.

Strategies

Vegetative barriers

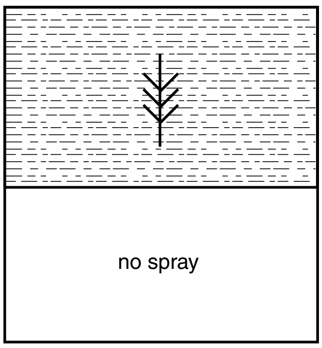
Buffer vegetation barriers may be planted and maintained on downwind edges of fields and properties, adjacent to susceptible areas.

A vegetative barrier is usually a tree or shrub line that is located on the downwind side of a sprayed area to protect an area susceptible to spray drift. Vegetation is sometimes planted deliberately to filter spray drift from the environment. However, the planting of vegetative buffers should be regarded as supplementary to primary methods of drift reduction set out in these principles. Vegetation barriers reduce spray drift by filtering the air as it flows through the porous barrier.

Strategies

Fallow buffer strips

Where an in-crop or vegetation buffer cannot be used to mitigate spray drift, off-target deposition can be reduced by establishing a downwind open fallow buffer zone.



Larger buffer zones may be required where in-crop or buffer vegetation cannot be used to intercept pesticide drift. Fallow buffer zones rely mainly on distances and can vary considerably depending upon specific pesticide or application scenarios and label requirements. Some examples are 200 m (ground application of endosulfan in cotton), 300 m (Queensland DNR Planning Guidelines), and 750 m for the aerial application of endosulfan in cotton (LDP application).

1.3. Communication

Principle

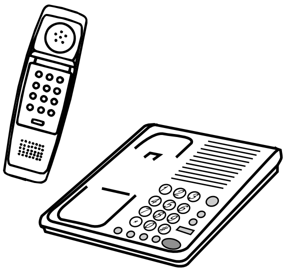
Communication with neighbours and stakeholders about proposed spraying activities will promote the development of cooperative spray management strategies and help avoid future conflicts.

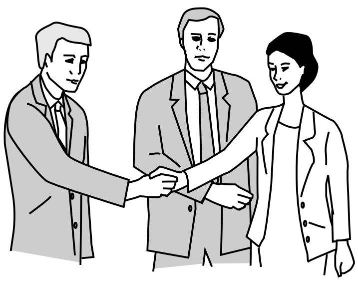
Many spray drift incidents can be avoided or their impact reduced if neighbours, contractors and sometimes the local community are advised and consulted prior to application. In some areas, local chemical liaison committees exist to foster close working relationships with growers, chemical users and concerned community members.

Strategies

Who, when and how?

- The chemical user should communicate with neighbouring properties and other stakeholders regarding anticipated spraying schedules and activities prior to the season and before spray application, particularly where a request has been made to provide such information.
- All parties should try to agree on the method of communication. Verbal contact by phone may be regarded as sufficient by some. Written advice may be preferable in other situations.
- Regular communication with local pesticide liaison committees, consultants and applicators should also be undertaken. Detailed communication may be needed for specific neighbours in susceptible situations.





1.4. Safe practices and personal protective equipment

Principle

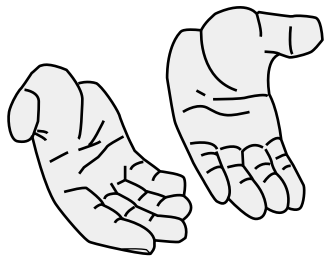
Always consult the pesticide label before undertaking any mixing, loading or spraying.

Those responsible for the selection, purchase, transport, storage and application of farm chemicals all have a responsibility under legislation to minimise any potential risk to other people, livestock and the environment. Where hazardous chemicals are to be used, chemical users have responsibilities under current Commonwealth and State/Territory legislation. The pesticide label and corresponding Material Safety Data Sheets (MSDS) contain detailed information on the use of the pesticide and these directions must be understood and followed.

Strategies

Safe practices

- Chemical users must never eat, drink or smoke when using agricultural chemicals (pesticides).
- Chemicals must never be stored in unlabelled containers or transferred to any non-original container.*
- Chemical users must always wash hands and skin exposed to chemicals immediately.
- Chemicals must always be kept in a lockable store out of the reach of children and animals.
- Dispose (or spray out) unused spray mixture and rinsate in accordance with State legislative requirements.
- Use closed mixing methods wherever possible.
- Wherever possible purchase products available in containers that are recyclable or refillable by the manufacturer.

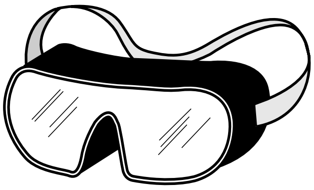


* Chemicals must never be stored in unlabelled containers. When necessary, the contents of leaking containers should always be transferred to a labelled container of the same material as the original until a properly labelled replacement container of the same type as the original can be obtained.

Strategies

Personal protective equipment (PPE)

- Always consult the label regarding appropriate PPE.
- Protective clothing and equipment should be checked before use, and cleaned and checked after every day's use.



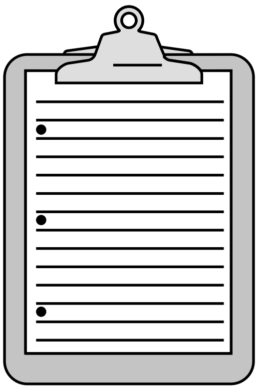
When preparing and mixing sprays, unless otherwise specified on the label, washable/disposable overalls, rubber or PVC gloves, PVC apron, rubber boots, face shield and washable hat should be worn.

When applying chemical sprays, unless otherwise specified on the label, washable/disposable overalls, rubber or PVC gloves, rubber boots, and washable hat should be worn. When use of a respirator is specified, its use and manufacture must comply with Australian Standards 1715-1994 and 1716-1994. All PPE should conform to current Australian Standards.

Strategies

Chemical risk reduction

- Before chemical application, alternative pest control methods (eg. Cultural, mechanical or biological control) should be considered.
- If chemical control is selected, only products registered for that purpose on that crop should be used, and products least harmful to non-target organisms and the environment should be chosen.



Strategies

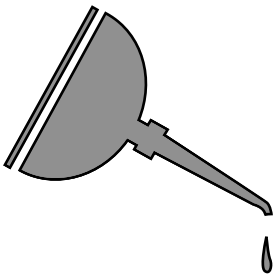
Establishing chemical details

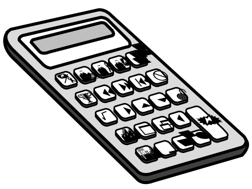
- The chemical user must read (or have read to them) and understand the pesticide product label.
- The chemical user should have access to and understand the current material safety data sheet for each product used.

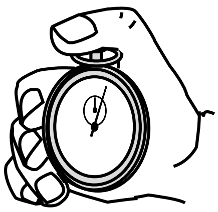
Strategies

Maintaining equipment

- Spray equipment should be maintained and operated according to the manufacturer's instructions.
- All spray equipment should be checked regularly for wear, damage, leaks and specification (nozzle type, etc.).
- All spray equipment should be regularly calibrated and performance-checked to ensure the correct application rate of material is applied. calibration records should be kept.
- Decontaminate spray equipment after use. Note any label instructions.







1.5. Weather

Principle

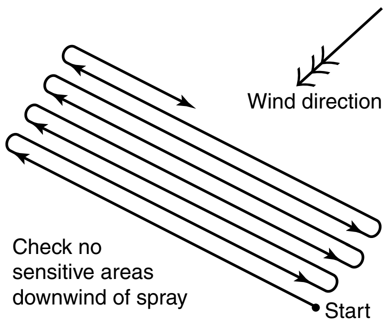
Weather conditions should be within acceptable limits for the safe and effective application of pesticides.

The weather plays an important role in controlling the fate of pesticides applied as sprays. The chemical user should check that weather conditions are within acceptable limits before spraying takes place. It is essential that a person engaged in spraying is aware of the effects of wind speed, wind direction, temperature, humidity and most importantly, atmospheric stability, on spray drift. Low cost hand-held weather meters (anemometers and psychrometers) are available to monitor these parameters. The purchase of meteorological station data loggers is recommended for larger enterprises regularly involved in the application of agricultural chemicals.

Strategies

Wind speed and direction

- Measure wind direction, wind speed, temperature and humidity prior to and during spray application.
- Sprays should be applied when the wind direction is away from sensitive areas.
- Spraying should not take place if the wind is light and variable in strength or direction.
- Chemical users should be alert to changes in wind direction and modify or cancel a spray program as necessary.
- Wind speed should be between about 3 and 15 km/h for most spraying operations.
- Spraying should, where possible, be carried out with a cross-wind, working into the wind towards the unsprayed area.



The most commonly cited wind speed limit for general purpose spraying is 15 km/h, 8 knots or 4 m/s. Above about 15 km/h, the airborne movement of medium and large droplets downwind from the intended target area may be excessive. In general terms the stronger the wind, the further droplets are able to travel; the smaller the droplets, the further they are able to travel (as their fall speed is much lower). It should be noted, however, that turbulence and atmospheric stability also heavily influence the movement of small droplets.

Spraying in winds exceeding about 15 km/h may require careful consideration of the enhanced risk and the adoption of specific strategies to avoid the off-target impact of any spray drift. Under these circumstances, a wide buffer zone may need to be established outside the downwind boundary of the sprayed area.

Strategies

Temperature and humidity

- Spraying should ideally take place when temperatures are at their most favourable (in a 24-hour cycle).
- Spraying of water-based sprays should not take place under conditions of high temperature and low humidity, eg. when the wet bulb depression (a measure of evaporation potential) is greater than about 10°C.

Whirling psychrometer

Whenever possible, spraying should be avoided in high air temperatures. Water-based sprays evaporate, particularly when air temperatures are high and the relative humidity is low. Evaporation reduces the droplet size of aqueous sprays as the droplets move through the air. Initial droplet size may be increased to compensate for this phenomenon. High temperatures can also mean the onset of unstable atmospheres that may prevent droplets reaching the intended target area.

Wet bulb depression is defined as the difference in wet bulb and dry bulb temperatures, as measured, for example, using a hand-held whirling psychrometer. High temperatures (>30°C) combined with low relative humidity (<40% ie. a wet bulb depression ΔT >10°C) can increase the rate of evaporation of water-based sprays and may subsequently increase spray drift.

Strategies

Atmospheric stability

- Spraying should ideally take place when atmospheric conditions are neutral.
- Do not spray during highly unstable conditions.
- Spraying should not take place when surface temperature inversion conditions exist.
- Where appropriate, a smoke-generating device can be used to determine atmospheric stability.

Stability is a term used to describe the vertical movement of air in the atmosphere. If atmospheric conditions are unstable, the dispersion of spray upwards may be high, increasing the amount of spray that enters the atmosphere (Figure 2). In contrast, the dispersion rate of droplets may be low in stable atmospheric conditions, leading to high off-target deposition of spray at ground level.

If the sky is clear at night, the ground can lose heat rapidly in the dry atmosphere and cool air layers adjacent to the soil surface. Under these conditions, air close to the ground becomes cooler than air above. Since this is opposite to the normal condition of the atmosphere (temperature decreasing with height), the condition is called a surface temperature inversion. Temperature inversions tend to suppress the vertical movement of air and therefore, in effect, present a barrier to the transport of small droplets to the crop canopy. Inversions usually form under very low wind speed conditions. Spraying should be avoided under such circumstances since small droplets are capable of remaining airborne for long periods within the inversion layer and can cause severe damage several kilometres away from where spraying took place.

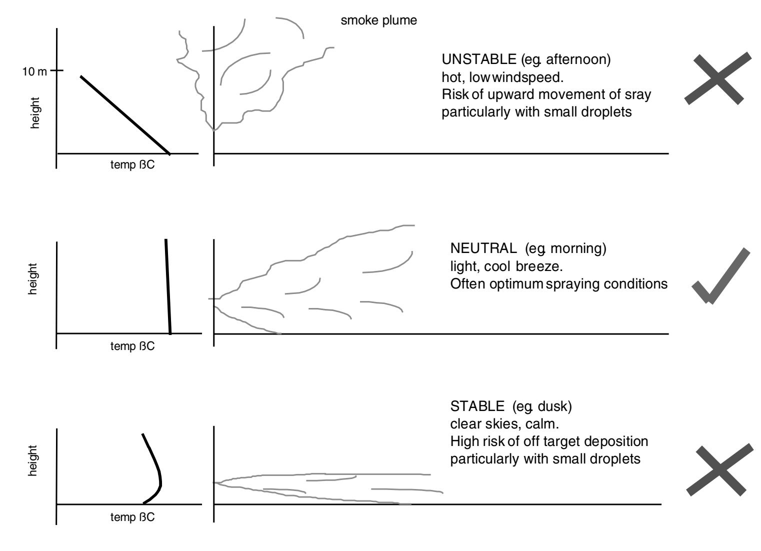


Figure 2. Basic guide to air stability – Behaviour of smoke or dust under various conditions of atmospheric stability.

Spraying should therefore ideally take place in neutral atmospheric conditions (Figure 2). The stability of the atmosphere can be assessed using smoke, or by driving a vehicle along a dusty track. Concentration of smoke or dust within a thin layer can indicate the presence of a surface temperature inversion.

1.6. Spray application technology

Principle

Spray application systems should be operated to minimise the potential for spray drift.

The most appropriate spray application equipment for a particular task will deliver droplets of the appropriate size in a way that maximises their deposition on the target. Particular types of spray application equipment are designed for specific purposes – application equipment designed for broad-acre crops is unlikely to be suitable for use in orchards. Spray application equipment should be properly maintained, calibrated and operated to maximise efficiency and avoid excessive spray drift.

Strategies

Droplet size

Chemical users should select nozzles according to the correct BCPC/ASAE droplet size classification, as indicated by nozzle manufacturers.

DG TeeJet® Even Flat Spray Tips

(bar)	DG95015E	DG9502E	DG9503E	DG9504E	DG9505E
2.0	M	C	C	C	C
2.5	M	M	C	C	C
3.0	M	M	M	C	C
3.5	M	M	M	M	C
4.0	M	M	M	M	M

Reference page 49 for more information.

Turbo TeeJet® Flat Spray Tips

(bar)	TT11001	TT11015	TT11002	TT11003	TT11004	TT11005
1.0	C	C	VC	VC	VC	VC
1.5	M	C	C	VC	VC	VC
2.0	M	M	C	C	VC	VC
2.5	M	M	C	C	C	VC
3.0	M	M	M	C	C	C
3.5	M	M	M	C	C	C
4.0	M	M	M	M	C	C
4.5	F	M	M	M	C	C
5.0	F	M	M	M	C	C
5.5	F	M	M	M	C	C
6.0	F	M	M	M	C	C

Reference page 28 for more information.

Turbo FloodJet® Flat Spray Tips

(bar)	TF-2	TF-2.5	TF-3	TF-4	TF-5	TF-7.5	TF-10
0.7	VC	VC	VC	VC	VC	VC	VC
1.0	VC	VC	VC	VC	VC	VC	VC
1.5	VC	VC	VC	VC	VC	VC	VC
2.0	VC	VC	VC	VC	VC	VC	VC

Reference page 35 for more information.

Drift Reducing Spray Tips

BCPC (ASAE S572) nozzle classification system.

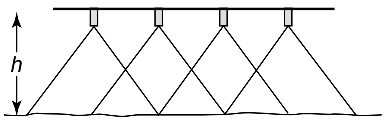
Droplet size is probably the single most important factor controlling pesticide spray drift. Because large droplets fall towards the ground significantly faster than small droplets, the airborne transport of droplets is significantly reduced if small droplet production is kept low.

A classification system based upon the British Crop Protection Council (BCPC) and now the American Society of Agricultural Engineers S572 international spray classification system enables nozzles to be selected according to spray quality. Nozzles in this scheme are classified according to the size of droplets that are generated using broad categories, ie. fine, medium, coarse, very coarse and extra coarse. Chemical users should consult the nozzle manufacturer's data sheets to select nozzles that have been tested and found to have the appropriate droplet size and flow rate at the required operating pressure.

Strategies

Release height

- Release height (*h*) of the spray should be as low as possible, consistent with nozzle specifications and coverage requirements and any label direction.
- Boom height should not exceed optimum heights specified by the nozzle manufacturer.



Release height (*h*) of the spray is an important factor influencing spray drift levels. The higher droplets are released, the greater the potential for drift. Adequate boom stabilisation is essential, especially on uneven ground. Boom height may be lowered to produce less spray drift, although modification to nozzle number, type and orientation is usually required to maintain an even spray pattern. The use of wide-angle flat fan nozzles (eg. 110°) usually permits lower boom heights to be utilised.

Strategies

Spray pressure

Spray pressure should be as low as possible, and consistent with nozzle specifications and coverage requirements.

When the pressure of a ground rig spray boom is increased, most hydraulic nozzles generate a finer droplet spectrum. To reduce drift potential, low pressures should be used. Many nozzle manufacturers now provide hydraulic nozzle tips that can be operated as low as 1 bar (14 psi). Spray volume should be controlled by changing nozzles, not by changing pressure, (ie. to increase flow rates select nozzles with larger orifices).

On aircraft in flight, the droplet size generated by some hydraulic nozzle systems is sometimes *increased* when hydraulic pressure is increased because the relative velocity between the spray liquid and local air velocity is effectively decreased. Agricultural spray pilots should consult the aircraft nozzle manufacturer's information.

Strategies

Hand-held application

- Chemical users should ensure the motion and height of the spray lance is kept to a minimum.
- Spray nozzles should be held at a constant height sufficient to produce an even spray pattern consistent with nozzle specifications and coverage requirements.

Strategies

Orchard spraying

- Chemical users should ensure that airblast sprayers are configured to direct spray into the crop canopy.

- Airblast sprayers should not be used to spray the downwind edge of an orchard (downwind side of the outer row) when susceptible areas within the awareness zone are located downwind of the field edge.

Airblast spray machines direct high-speed air into the crop canopy. Chemical users should ensure that spray droplets are contained within a tree canopy and not directly sprayed into the air above a canopy. Where appropriate, air deflectors should be used so that air produced by an airblast sprayer is directed into the canopy and not lost between the rows.

Downwind susceptible areas within the awareness zone should be identified during spraying and steps taken to reduce drift by:

- using existing rows of trees adjacent to the susceptible area as unsprayed buffers.
- using equipment that directs the air out one side of the sprayer and spraying the other row or rows from one direction only (away from the susceptible area).

Strategies

Aerial application

- Sprays should be applied only when the aircraft is straight and level above the crop.
- Smoker devices should be fitted to aircraft to enable pilots to observe and monitor changes in wind direction and turbulence.
- Where rotary nozzles are used, they should be fitted with systems or methods capable of monitoring rotational speed.

Wing-tip vortices are increased when an aircraft descends into and pulls up out of a field. To reduce the height of release of pesticide droplets, the spray system should only be activated when an aircraft is flying straight and level above a crop.

The droplet sizes generated by rotary nozzles, eg. Micronair™, are in part determined by the speed of rotation of the unit. Droplet spectra information data can be readily obtained in the laboratory and is available from many manufacturers. Rotary units should be operated specifically within nominated rotational speed windows and the use of, for example, onboard transducers for monitoring rotational speed should be encouraged.

1.7. Training

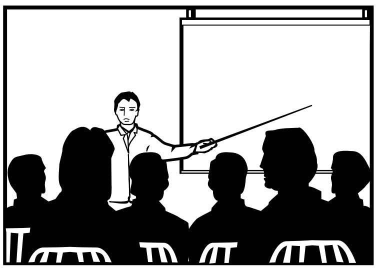
Principle

Training of chemical users can improve the efficiency of their spray applications and reduce the likelihood of off-target spray drift.

Strategies

Training and licensing

- Agricultural chemical users should be qualified according to relevant State/Territory training and accreditation requirements.
- All chemical users should be encouraged to undertake farm chemical user training as a minimum requirement for the use of agricultural chemicals.
- Where required, aerial operators, pilots, and commercial ground chemical users must be licensed according to State/Territory and Commonwealth regulatory requirements and be appropriately trained. This may include, for example (for pilots), holding accreditation under the Aerial Agricultural Association of Australia's Operation Spraysafe Program.



1.8. Record-keeping

Principle

The chemical user should maintain up-to-date records of chemical usage and spray operations on the property.

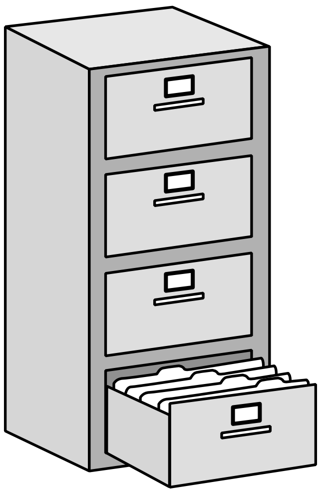
The chemical user should produce a spray report after each and every spray operation. The report should include the date, time, area sprayed, amount and name of chemicals applied, recorded application rates, chemical user(s) involved, equipment used, nozzle type, settings (spray pressure, blade angle or unit RPM, where appropriate) and meteorological conditions (wind speed and direction, temperature and humidity).

Chemical users must comply with any compulsory record-keeping requirements that apply in their State/Territory, or that are specified on the label or in the approval of registered agricultural chemicals. This could include retaining records of application for a set period of time, eg. 2 years or more.

Strategies

Record-keeping

- The following information should be recorded:
  - Awareness zone chart
  - Calibration report
  - Spray report – including weather observations
  - Chemical listing – a register of all chemicals used on farm.
- The chemical user should hold a copy of Material Safety Data Sheets (MSDS) for all products used on the property.
- Chemical users should ensure that Material Safety Data Sheets are readily available and consulted prior to application.
- Chemical users should retain records in accordance with relevant legislative requirements.



MSDS are available from the supplier or manufacturer of the farm chemical.

2

Supporting information

2.1. Property management planning

2.1.1. Crop planning

Spray drift management starts when a farm or enterprise is planned or developed. Much can be done to mitigate spray drift during the planning phase of land development by identifying areas where pesticide application may conflict with adjacent land use. For example, the location of an orchard next to a school, or a cotton crop next to a travelling stock route, will increase the risk of insecticide drift onto humans or livestock. Similarly, proximity of tomatoes to sugar cane, or wheat to a vineyard, will increase the risk of herbicide spray drift damage to crops.

2.1.2. Integrated pest management

In an overall spray drift operational plan, methods should be considered that reduce or remove the requirement to spray. Such methods include improved cultivation practices, crop hygiene, crop rotation, biological control, use of resistant cultivars, genetically modified crops, augmentation of beneficial insects and the adoption of chemical use strategies that minimise pest resistance.

2.1.3. Chemical selection

Farm chemicals must be selected that are registered (or approved) for the intended crop, pest and purpose. Where alternative products exist, pesticides should be chosen that are least harmful to non-target organisms and the environment. Selection of farm chemicals should conform to relevant pest resistance management plans.

2.1.4. Preparation of property plans

Chemical users should establish property plans that facilitate and support pesticide application best practices. In preparing a property plan, the user should communicate with neighbours regarding the identification and location of all sensitive or potentially sensitive areas. The plan should be up-to-date and enable spray application hazards to be identified (eg. the location of overhead powerlines). The property plan should also be used to identify the location of vegetative buffers that can be used for spray drift mitigation. Importantly, the property plan can be used to enable the chemical user to establish awareness zones around the area or paddock to be sprayed.

2.1.5. Awareness zones

The purpose of an awareness zone is to identify sensitive areas near to a farm property. A sensitive area is defined as any area that could be adversely affected by spraying activities. Common examples of sensitive areas include susceptible crops, native flora and fauna, waterways and wetlands, bees, non-target plants and animals, buildings and sites of habitation. If sensitive areas are present or become established within the awareness zone, details should be recorded and, if necessary, expert advice sought.

The width of the awareness zone should take into account the degree of sensitivity of the area in question and also if the area is subject to local meteorological effects such as cold air valley (katabatic) wind flows. Small distances (eg. 100 m) might be appropriate for spraying small horticultural areas with hand-held equipment, whereas large distances (eg. 5 km) might be required for the aerial application of agricultural chemicals in large monocultures.

These distances are not intended to be precise, nor are they intended to represent the required downwind buffer distance. The awareness zone is purely an aid to encourage all applicators to gain an understanding of areas that lie ‘over the fence’ so appropriate management decisions can be made. Owner/managers are encouraged to develop their own appropriate spray drift assessment zones. The zone should be used to aid the survey of areas or buildings outside a field to be sprayed that may be potentially sensitive to spray drift.

Important note

The establishment of a drift awareness zone at a given distance does not imply that spray droplets can or cannot be transported in air beyond that distance. The concept and use of an awareness zone should not be confused with the use and implementation of buffer zones.

2.2. Establishment of buffer zones

Land use management plans should incorporate sufficient land (that is not chemically sensitive) around fields so that chemical usage does not impact upon other adjacent enterprises. For spray drift management, a buffer zone is an area of land located on the downwind side of a sprayed area used to protect an area susceptible to spray drift.

2.2.1. Fallow and in-crop buffer strips

Spray drift deposition over fallow ground can be predicted using computer models (see Section 2.6.17.). Figure 3 shows how a simulated pesticide spray is built up over the crop as a result of a number of sequential passes of the spray equipment. If spraying was continued right up to the downwind boundary of the paddock, the hypothetical model shows that a small percentage of the spray would be deposited outside the downwind boundary of the field. This phenomenon is normal and can occur when using most types of pesticide application equipment.

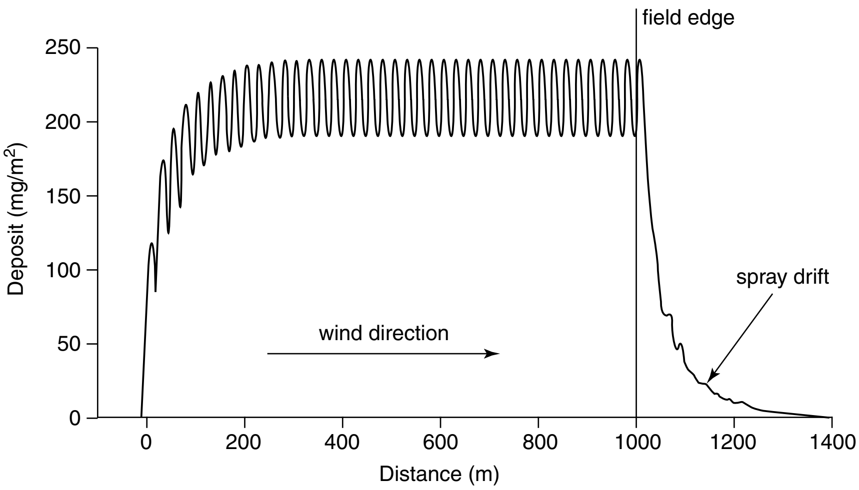


Figure 3. A diagrammatic representation of application (Gaussian diffusion model) across a field showing the sequential build up of deposit across a field and downwind deposition profile.

The driftable fraction of the spray leads to the formation of an off-target deposition tail that extends downwind of the sprayed field. By establishing a wide buffer distance on the downwind side of a sprayed area, the spray drift deposit on neighbouring areas can be reduced.

For individual chemicals where the Predicted Environmental Concentration (PEC) is known, it is possible to determine the required buffer distance from a sensitive target. The buffer distance required is the point at which the PEC becomes less than the No Effect Concentration (NEC). This distance will vary according to specific application parameters, meteorology and toxicity of the chemical. Recommended or mandatory buffer distances are increasingly being incorporated into product labels.

2.2.2. Field splitting

Field splitting involves partially treating a particular field, leaving the required buffer distance of crop untreated until there is a favourable change in the wind direction. Field splitting is a useful spray drift management tool for both ground spraying and aerial application. For example, if the wind is blowing from the south, the chemical user could just treat the southern half of the field, and return to spray the northern half of the field at a later date when the wind direction is more favourable. Subsequent follow-up sprays should take into account the possibility that the initial unsprayed area may have been subject to spray drift, which may result in chemical deposits on that area that exceed Maximum Residue Levels.

2.2.3. Vegetative buffers

Trees, shrubs and crops planted downwind of an agricultural area can be used to recover droplets and thereby mitigate spray drift. The aim of vegetative buffers is to use the natural surfaces (including leaves, stems, flowers and seeds) of the tree/shrub to catch pesticide droplets as they move in the air through or over the vegetation.

The processes by which crop or barrier vegetation provides protection against particle deposition further downwind can be described in two different ways, acting respectively at regional and local scales (although the processes overlap to some extent). Regional protection occurs by downward deposition from the air flowing *over* an extensive buffer strip, while local protection occurs by deposition or filtering as air flows *through* a single porous barrier (Raupach *et al* 2000).

2.2.4. Regional protection (wide vegetative buffer strips)

Regional protection occurs when particles are extracted from the air flowing over an extensive 'buffer' area with a high potential for absorbing particles, such as a

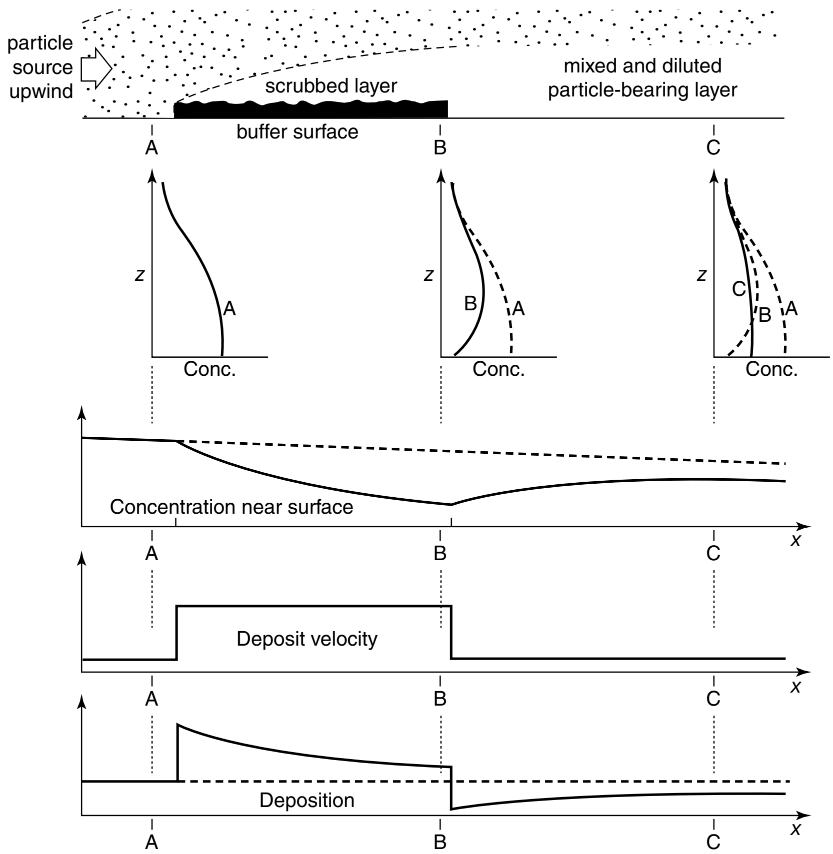


Figure 4. Diagram illustrating droplet deposition downwind of a spray area being affected by a buffer surface with a high potential for droplet capture (after Raupach *et al* 2000).

wide vegetative buffer strip. The mechanism for this type of protection is illustrated in Figure 4.

- A relatively deep layer of particle-laden air, tens to hundreds of metres deep, is assumed to be produced by a particle source some distance upwind. The further upwind the source, the deeper is this layer. This incident flow is represented by point A.
- The particle-laden air encounters a highly absorbing buffer surface, typically consisting of relatively tall vegetation with fine leaves. Particles are mixed downwards and deposited to this buffer surface, reducing particle concentrations in a 'scrubbed' air layer that deepens with increasing distance (x) across the buffer surface; see point B.
- Beyond the buffer surface, deposition to the downwind receptor surface is reduced. This occurs both because of the low particle concentrations in the scrubbed air layer itself (a relatively short-range effect), and also because particle concentrations in the entire particle-bearing layer are reduced by mixing and dilution of the remaining particle-laden air with the relatively clean air in the scrubbed layer (a long-range effect).

2.2.5. Local protection (narrow vegetative filter barriers)

Local protection occurs when particles are filtered out of the air flowing through a porous vegetative barrier, such as a windbreak or narrow vegetative filter barrier. A narrow barrier is long in the cross-wind direction and narrow in the along-wind direction. The mechanism is illustrated in Figure 5.

- As in the case of a buffer strip, the porous barrier is assumed to be immersed in a particle-laden air flow much deeper than the height of the barrier itself, so that the incident particle concentration is approximately uniform with height; see point A.
- Some of the oncoming air is filtered through the barrier, while some passes over it. Particle concentrations are not changed in the air flowing over the barrier, but are strongly reduced in the through-flowing 'bleed flow' by deposition onto leaves and stems in the barrier (Figure 5, point B). There is a strong reduction in particle deposition on the surface in the immediate lee of the barrier, caused by both the reduced particle concentration and the reduced wind speed in this region (the 'quiet zone'). This region extends to a downwind distance of around 3 to 10 times the height of the barrier.
- Particles in the flow above the barrier are mixed downwards into the quiet zone with increasing distance (x) from the barrier. Hence, near-surface particle concentrations and surface deposition both increase, eventually recovering approximately to their values upwind of the barrier. The local protection provided by a single barrier therefore effectively reduces deposition in the immediate lee of the barrier, but does not have much impact on concentrations further downwind.

Between 1991 and 1993, a series of 26 measurements were taken of airborne spray concentration in front of and behind a series of narrow tree lines by the University

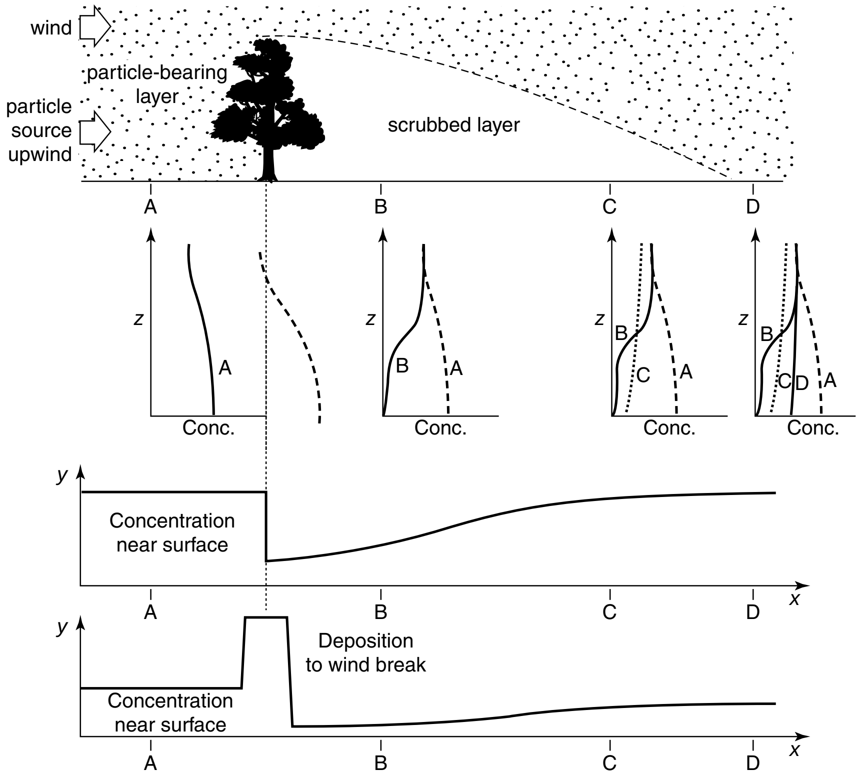


Figure 5. Diagram illustrating droplet deposition downwind of a spray area being affected by a porous vegetative barrier (after Raupach *et al* 2000).

of Queensland. From these trials it was found that in most cases between 10% and 20% of the level of spray recovered on a monitoring tower placed in front of a vegetative array was recovered on a monitoring tower located behind the tree line. Movement of droplets over the top of the tree line was observed in most of these trials.

2.2.6. Vegetative buffer design

Plant surfaces that present a small frontal area to the moving droplets are the most successful at catching droplets. Trees, such as the River She-Oak (*Casuarina* spp), that have thin needle-like foliage and numerous small branches are particularly suitable. Large leaves that are covered in small hairs can also be very efficient at removing droplets. Most natural surfaces are not smooth. Plants may have a complex rough surface comprising small protruding spikes or hairs and leaf veins. All these factors help to increase the catch efficiency of the plant. Movement of the leaves caused by the flow of air around shrubs and trees also increases the catch efficiency.

In designing a vegetative buffer element, the primary aim is to maximise the catching surface for the spray droplets whilst at the same time minimising the amount of airflow deviation around the structure. This requirement to minimise the airflow deviation may be in contrast to trees used for windbreaks, where the aim is to direct the air away from the downwind side of the buffer. A breeze passing through a vegetative barrier will tend to enhance conditions for capture. However, it should be noted that the use of elevated winds can also increase the drift potential of a spray.

If a dense barrier is presented to an airflow, air tends to flow up and over the barrier. This is illustrated in Figure 6 (upper diagram) where the airflow deviation over a solid board (0% porosity) placed in a wind tunnel is shown. The direction of the air around the barrier is illustrated by light tufts of wool placed on the inside wall of the wind tunnel in the air stream. The region directly behind the barrier is characterised by low pressure and turbulent eddies.

During spray application, it is the small droplets (under 100 μm) that are most prone to drift. Because small droplets move readily along in an air stream, they can also be easily carried by an air stream in, above and around buffer vegetation. When air is deflected above a low porosity tree line, small droplets are also carried over the top of the barrier. Dense, low porosity structures are less effective in trapping spray drift except in the immediate region behind the barrier.

A porous barrier, however, allows some air to pass though its structure while still deflecting some airflow over the top. This is illustrated in Figure 6 (lower diagram) where a wire mesh with 50% porosity (50% solid and 50% open) was placed

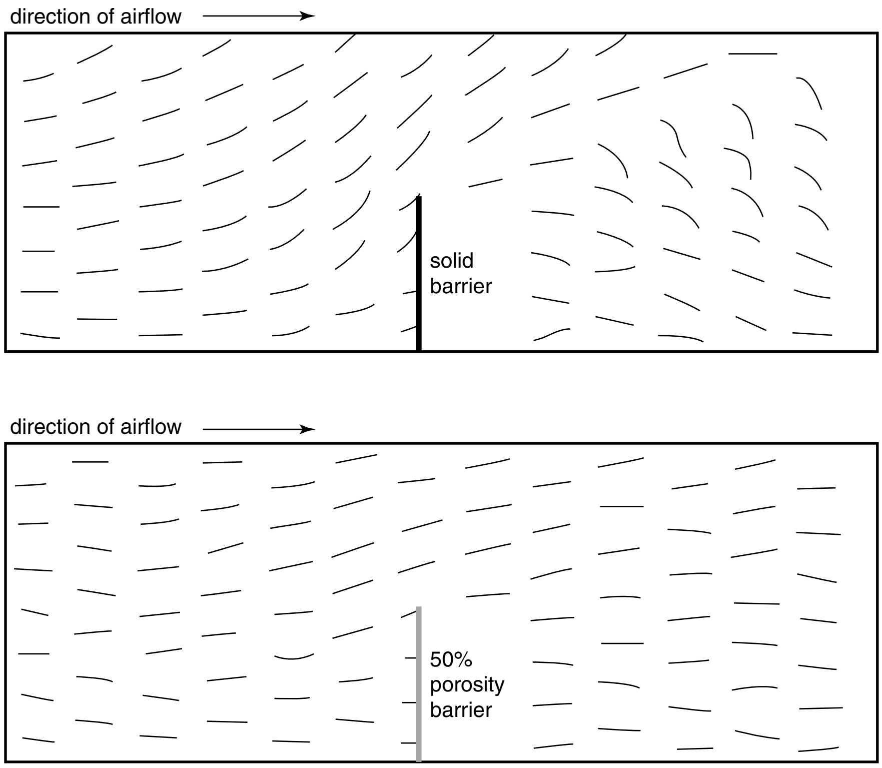


Figure 6. Effect of barrier porosity on airflow characteristics.

in a wind tunnel. The figure shows that there was less deviation of air over the top of the barrier compared to the solid barrier. The airflow behind the barrier was also straighter and less turbulent than behind the solid barrier. With a porous barrier, droplets can be carried through a buffer and this increases the chance of capture within the structure. A porous barrier can effect a greater removal of spray droplets than the solid barrier.

Because of this phenomenon and the action of turbulence on the dispersion of a spray cloud, a vegetative barrier must be higher than the release height of the spray. As a general guide the minimum height of the buffer should be double the release height. For example, if spraying is conducted by hand at a release height of 1 metre, then the buffer height should be at least 2 metres. However, protection from spray drift is only in the region of 3–10 barrier heights downwind of the barrier.

The closer the vegetative buffer is to the release point, the greater the proportion of spray that will be intercepted. Figure 7 shows that a vegetative buffer at position A would tend to intercept a greater proportion of a spray cloud than a buffer located at position B. The concentration through the spray cloud is not constant and usually tends to be greatest near ground level and near the release point. A buffer at position B could still be expected to intercept a proportion of the airborne droplets at the height of the barrier but has no effect on the spray cloud above the barrier.

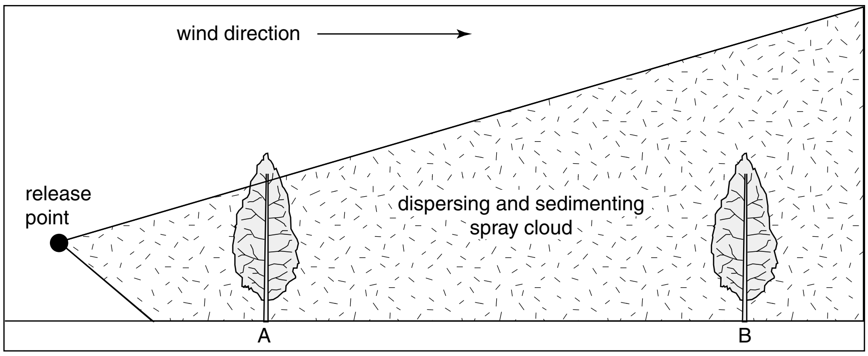


Figure 7. Effect of distance from release point.

In summarising the data, the following factors should be taken into account when designing the layout of trees for spray drift reduction:

- A band of porous trees will tend to minimise air disturbance, while still providing a large number of catching surfaces
- Thin, rough foliage should extend from the base to the crown.
- Trees with small and/or hairy leaves will tend to maximise droplet capture.
- The vegetation should provide a permeable barrier that allows air to pass through the buffer.
- Mixed plantings of trees may be required to ensure there are no gaps in the lower canopy.

- Tree height should be at least double the release height of the spray.
- The vegetative buffer should be as close as practicable to the spray zone.

2.2.7. Case study, QDNR guidelines

In 1997, the Department of Natural Resources in Queensland introduced *Planning Guidelines: Separating Agricultural and Residential Land Uses.* The Guidelines have the following objectives (DNR 1997, 3):

1 To protect the use of reasonable and practicable farming measures that are practiced in accordance with the Environmental Code of Practice for Agriculture and associated industry-specific guidelines.

2 To minimise scope for conflict by developing, where possible, a well-defined boundary between agricultural and residential areas and not interspersing agricultural and residential areas.

3 To minimise the impacts of residential development on agricultural production activities and land resources.

4 To minimise the potential for complaints about agricultural activities from residential areas.

5 To provide residents with acceptable environmental conditions in residential areas that are located adjacent to agricultural production areas.

The Queensland Guidelines specify a minimum spray drift buffer width of 20 metres planted with trees and at least 10 metres clear of vegetation to either side of the vegetated area to give a total buffer width of 40 metres (DNR 1997, Appendix 2). A schematic cross-section of this arrangement is shown in Figure 8. A 20-metre clear area (10 metres either side of the buffer) is included in the design to provide a fire break, allow access to the buffer for maintenance and limit solid structures immediately next to the buffer elements. Provided the requirements of the guidelines can be met by other means, the guidelines do allow buffer layouts to be altered. The Queensland Guidelines provide a sound minimum basis for the construction of buffer areas between conflicting land use. It should be noted that buffer area requirements will change with application type, chemical formulation, weather conditions, etc.

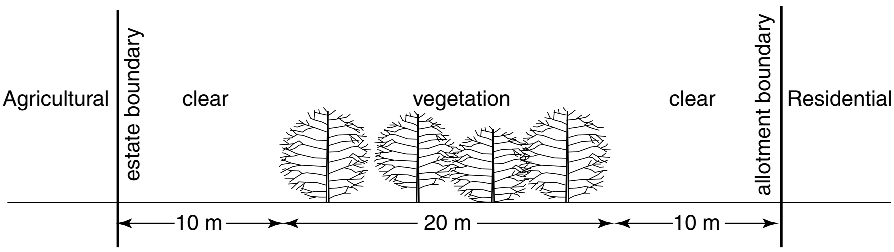


Figure 8. Schematic illustration of vegetative buffer required for spray drift mitigation as defined by *Planning Guidelines: Separating Agricultural and Residential Land Uses* (DNR 1997).

2.3. Communication

2.3.1. Neighbours

By advising neighbours of spray application requirements, sensitive areas can be identified and precautions taken by both the chemical user and the neighbour to minimise the contamination of off-target areas. Chemical users should hold pre-season discussions with owners/occupiers of neighbouring property and other stakeholders regarding anticipated spraying schedules. Information regarding spraying activities should be made freely available, particularly where a request has been made. The importance of effective communication with adjacent land users is paramount. Conflict over spray drift issues can often be avoided if neighbours, contractors and sometimes the local community are advised and consulted prior to application.

2.3.2. Community groups

Regular communication with local pesticide liaison committees, consultants and applicators should also be undertaken. Effective communication processes are time-consuming and may require a high level of commitment from the chemical user. Detailed communication may be needed for specific neighbours in susceptible situations. In some instances, local groups can be formed to foster closer working relationships between chemical users and concerned community members.

2.3.3. Methods

Contact by phone or email may be regarded as sufficient in most circumstances. However, other situations that may involve more complex scenarios may require communications to be recorded in the form of typed, signed and dated correspondence. Processes for conflict resolution should be clearly defined with agreed procedures for the initiation of regulatory action, if required.

2.4. Safe practices and personal protective equipment

2.4.1. Safe practices

Handling. After handling agricultural and veterinary chemicals, always wash your hands before eating, drinking, smoking or using the toilet, and after work. Ensure that smoking, drinking and eating are prohibited during any chemical handling.

Skin contamination. In event of contamination, drench skin and clothing with water, remove clothing, cleanse skin and hair thoroughly with soap and water. Rapidity in washing is most important in reducing extent of injury. Any injuries such as cuts or abrasions should be attended to immediately. Store contaminated clothing in a sealed plastic bag until it can be laundered.

Labelling and storage. All containers of chemicals must be labelled. Always store pesticides in the original, labelled container with the label plainly visible. Never store them in bottles or food containers that could be mistaken for food or drink for humans or animals. Accidental or unauthorised access to the storage area should be prevented. Possible risks to children and visitors not familiar with the hazards of chemicals should be anticipated. The store should be kept locked and have a childproof latch fitted. Construct the building so that it is secure and cannot be entered by anyone except authorised personnel.

Training. All persons employed on the premises should receive training appropriate to their duties and responsibilities, which should include the correct use of personal protective equipment and its proper maintenance. Employees should as a minimum be aware of relevant chemical hazards including fire risk and symptoms of poisoning, and know the action required in case of an emergency.

2.4.2. Personal protective equipment (PPE)

Reference to PPE may be found in the product label and MSDS as well as the relevant code of practice that may be available from State authorities. It is essential to adhere to label instructions regarding correct PPE – for example, PVC gloves may be incompatible with certain formulations. All PPE, including respirators, should conform to current Australian Standards. Unless otherwise specified on the label, when preparing and mixing sprays, the minimum protective clothing that should be worn includes washable or disposable overalls, rubber or PVC gloves, PVC apron, rubber boots, face shield, washable hat. Some product labels will require additional PPE to be worn.

All equipment, clothing, hats, gloves, boots, aprons, goggles and respirators should be thoroughly washed with soap and water each day or when spraying is finished, whichever is sooner. A spare set of clothing should be made available for each worker.

2.4.3. Material Safety Data Sheets (MSDS)

Material Safety Data Sheets should be obtained and read for every chemical used in an enterprise. MSDS are available from chemical suppliers and manufacturers. They should be stored alphabetically by trade name in a filing cabinet, within easy access of where chemicals are handled. A regular check should be made to make sure all MSDS are present, in good condition, and reflect current chemical stock holding.

2.4.4. Product labels

Agricultural chemical labels contain the following important information:

- Product name, active constituent(s), solvent(s)
- Poison schedule and any relevant Dangerous Goods information
- Precaution statements and drift warning statements
- Mixing, handling and storage instructions
- Crops (commodities) that the chemical may be used upon
- Pests for which the chemical is registered to control
- Dosage, timing and application instructions (maximum dosage and number of repeat applications)

- Withholding periods
- Safety directions, including details of required personal protective equipment (PPE)
- First aid instructions
- Disposal procedures and critical comments
- Manufacturer's details, including emergency contact numbers
- Date of manufacture and batch number (and expiry date for some products)
- NRA approval number

It is a legal requirement for the user to understand and adhere to label instructions. If for any reason the user cannot read the label, he or she must have the label read to them.

Farm chemical product labels now carry a unique number allocated by the National Registration Authority and which is known as the 'NRA Approval No.' The presence of the number is an indication that the product has been cleared for the purpose shown on the label. It also indicates that the NRA considers that following the label directions is adequate to ensure efficient pest management with no adverse impact on people exposed to or consuming produce treated with the chemical, on livestock or on the environment. The application of recommended label rates and the observance of any required withholding period prior to harvest will result in sprayed produce being at or below the legal Maximum Residue Limit (MRL) for the relevant farm chemical. The MRL has been derived from residue trials and a comprehensive study of the consumption data relating to the crops for which the chemical is registered. This data can then be assessed against the Acceptable Daily Intake (ADI) established from the toxicology evaluation of the chemical. While following label directions will not necessarily prevent spray drift, it is a legal requirement under State law and will protect both growers using the chemical and consumers of the treated produce.

2.4.5. Maintenance

Spray equipment should be decontaminated after use. Spray application equipment should be adequately maintained and regularly checked for wear, damage, leaks and specification (nozzle type, etc.). Maintenance records should be kept. Nozzles should be replaced when worn – for example, when variation in flow rate exceeds manufacturer's specification by 10%.

2.4.6. Calibration

All spray equipment should be regularly calibrated to check that the correct application rate of chemical is being applied. Calibration records should be kept.

If spray equipment is incorrectly calibrated, potential exists to contaminate sprayed land and off-target areas, and to damage crops. In addition, the efficacy and performance of the farm chemical may be compromised.

2.5. Weather

2.5.1. Wind direction

Differential heating of the ground and sea by solar energy causes air masses of varying temperature, humidity and pressure to develop. Air pressure gradients are established that cause air to flow from high to low pressure areas. Except near the equator, forces due to the curvature and rotation of the earth cause the air (in the southern hemisphere) to flow anticlockwise around high pressure areas (anticyclones) and clockwise around low pressure areas. It is this flow of air (on the large synoptic scale) that we experience as wind.

In hilly country, or on flat land close to slopes, farming areas can be subject to evening katabatic winds. As land cools, air immediately above the surface of the ground can be cooled resulting in that air becoming more dense and thus heavier than surrounding air. If cooling occurs on sloping ground, heavy air can flow under gravity to lower levels, resulting in the generation of local wind flows. The wind speed and direction above a crop are of prime importance to applicators. The wind largely controls not only the direction of spray after release from a sprayer (and thus its movement towards or away from the target area), but also the degree to which droplets are caught by the foliage or pest and the uniformity of deposit. Consequently, spraying with a wind direction selected to carry droplets away from known sensitive areas, as part of an operational plan, is a valuable drift control tool.

Droplet behaviour, particularly that of small droplets, is influenced by meteorological conditions. The influence of most parameters is well documented, particularly that of wind speed and stability (vertical air movement).

2.5.2. Wind speed

The effect of wind speed on spray drift is complex. For example, a strong wind may increase the downwind movement of a peak deposit of a spray, but may improve deposition in the canopy due to increased turbulence and enhanced catching efficiency. Drift can be shown to increase with increasing wind speed, but perhaps more importantly, severe drift can also occur under highly stable (inversion) conditions (see Section 2.5.6.). Strongly stable atmospheres often form under low wind speed conditions. Spraying in a light breeze is therefore ideal. With medium and large droplets, drift will increase as wind speed increases.

In the interest of good spray drift management, spraying in very strong winds, or when the wind is light and variable in direction, should be avoided. In the latter case it becomes difficult for an applicator to direct a spray away from the location of susceptible areas when the wind direction is not assured.

A wind speed limit of between 3 and 15 km/h is proposed as a drift mitigating strategy. If wind speed is outside these limits then spraying under most circumstances should be avoided. However, spraying could take place at wind speeds above 15 km/h if special dispensation is applied.

2.5.3. Temperature

Spraying in summer should usually be undertaken when temperatures are the most favourable, (in a 24-hour cycle). As temperature increases, water-based formulations and mixtures can be exposed to greater evaporation and this can lead to the formation of smaller droplets and therefore greater drift potential. High temperatures, for example, greater than about 30°C can also be an indicator of strong high atmospheric instability leading to a convective loss of spray to the atmosphere.

2.5.4. Humidity

The term 'relative humidity' (RH) is used to describe the dryness of the atmosphere. It defines the ratio of the amount of water that is contained in a sample of air to that which could be contained in the same volume of air if saturated at that temperature. Because it is a relative measure dependent upon temperature, the RH increases as the temperature drops and decreases with increasing temperature. It is therefore usual to find that over a crop canopy, maximum RH values are recorded at dawn. The relative humidity or wet bulb depression (delta T or ΔT) is easily measured in the field by using a whirling psychrometer. Consisting typically of two thermometers mounted on a small frame, the unit is rotated by hand in the shade for a few minutes until stable temperature readings are obtained. The bulb of one of the thermometers is covered with a moist wick that dries in the air and lowers the temperature of the bulb. The drier the atmosphere, the greater the amount of evaporative cooling and difference between the two bulb temperatures. Using suitable tables or calculators, it is possible to calculate the relative humidity of the air from these two temperatures. Alternatively, relative humidity may be measured directly using a solid state sensor. This method of measuring humidity is now commonly used in most weather stations. If delta T and the dry ambient air temperature are known, RH may be read using the following graph (Figure 9). To maintain delta T values below 10°C, RH and air temperature values

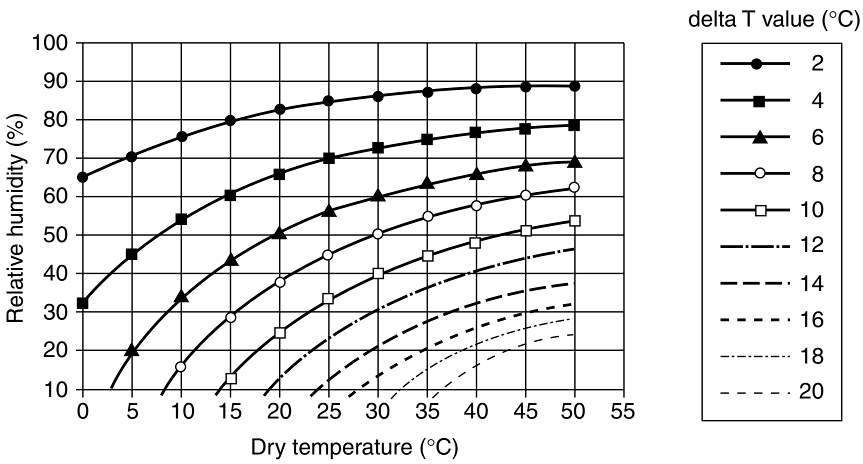


Figure 9. Relationship between dry temperature and relative humidity for various wet bulb depression or delta T values.

must be kept above the delta T = 10°C line. For example, to maintain a delta T of 10°C, if the dry temperature is 20°C, spraying should not be undertaken if the RH is less than about 25%. Similarly, if dry temperature is 30°C, spraying should not be undertaken if the RH is less than 40%.

2.5.5. Evaporation

When water-based droplets are released into the air by a sprayer, they tend to become smaller as molecules leave the outer surfaces of the droplets. This is called evaporation. Water, which is the most commonly used spray carrier, evaporates rapidly in Australian summer temperatures and therefore significant reductions in droplet size can occur after droplets have left the nozzle.

The problem is particularly acute for small droplets for the following reasons:

- The droplet surface area-to-volume ratio – as the size of a droplet decreases, there is an increase in the ratio between the surface area of a droplet and its volume. Consequently, a greater proportion of the volume of the droplet is exposed to the atmosphere as the droplet size decreases.
- As a droplet becomes smaller through evaporation, its sedimentation velocity, or rate of fall towards the ground, becomes slower. Hence a droplet remains airborne longer and is thus more susceptible to further evaporation as it becomes smaller.
- The rate of evaporation of a droplet is related to its size. Experiments have shown that water droplets smaller than about 150 µm evaporate about 27% faster than droplets above this size. This is due to a change in airflow that occurs about droplets smaller than this size. Above 150 µm, the airflow is separated from the base of a droplet and no evaporation occurs from this region. By contrast, the flow is attached everywhere on droplets less than about 150 µm and evaporation occurs from the whole surface (Spillman 1984).

Work done by Hall *et al* (1994), Riley *et al* (1995) and Teske (1998) supports the hypothesis of Spillman (1989), that rate of change of droplet diameter with time is linear for freely falling water droplets.

2.5.6. Stability

Stability is a term used to describe the vertical movement of air in the atmosphere. If atmospheric conditions are unstable, the dispersion rate of pesticide sprays may be high, increasing the amount of spray that enters the atmosphere. In contrast, the dispersion rate of pesticide droplets may be low in stable atmospheric conditions, leading to high off-target downwind movement of spray. Air turbulence levels are also low in stable atmospheric conditions and deposition within a canopy may also be low, contributing to the problem of spray drift. The main stability classes are summarised in Figure 10. This figure shows, for each primary condition of stability, a typical temperature gradient and an illustration of the likely dispersion pattern of a cloud of small droplets.

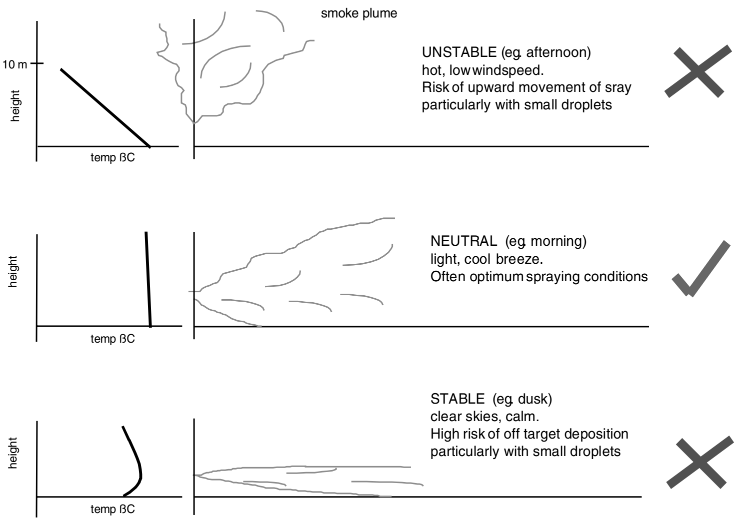


Figure 10. Basic guide to air stability – Behaviour of smoke or dust under various conditions of atmospheric stability.

2.5.7. Stable conditions

If vertical movement of air is suppressed, the atmosphere can be said to be stable. Under such conditions, a parcel of air is cooler and thus more dense than the surrounding air and tends to return to its original position before displacement. Vertical air movement tends to be suppressed and wind velocities are usually low. A stable atmosphere can occur on dry, cloudless nights when the land cools as long wave radiation (heat energy) is emitted by the ground. The ground then cools the air above it and a surface temperature inversion occurs. Under these conditions, the temperature increases with height for a finite distance instead of the normal lapse conditions.

2.5.8. Unstable conditions

A parcel of air displaced upwards from the ground (eg. by convective thermal effects) will normally move into a region of lower pressure and thus expand. This expansion is normally adiabatic (ie. there is no exchange of heat with the surrounding air) and results in the cooling of the air parcel. The rate of cooling is about 10°C per 1000 m. In normal summer conditions during the late morning and afternoon, air parcels generated in this way tend to rise and remain hot and thus lighter than the surrounding air. The air is said to be unstable and is characterised, should there be sufficient moisture in the atmosphere, by the formation of large cumulus clouds. Air made to rise under such conditions has a tendency to continue its upward motion. Usually thunderstorms develop in strongly unstable atmospheric conditions.

2.5.9. Neutral conditions

This is where stability is intermediate between 'unstable' and 'stable' and may represent the best conditions for spraying. Such conditions often occur during the early part of the morning.

2.5.10. Temperature inversion

If the sky is clear at night, the ground can lose heat rapidly in the dry atmosphere and cool air layers adjacent to the soil surface. Under these conditions, air close to the ground becomes cooler than air above. Since this phenomenon is opposite to the normal condition of the atmosphere (temperature decreasing with height), the condition is called a surface temperature inversion. Temperature inversions tend to suppress the vertical movement of air and therefore, in effect, present a barrier to the transport of small droplets to the crop canopy. Inversions usually form under very low wind speed conditions. Spraying should be avoided under such circumstances since small droplets are capable of remaining airborne for long periods above an inversion layer and can cause severe damage several kilometres away from where spraying took place.

Spraying should therefore ideally take place in neutral atmospheric conditions. The stability of the atmosphere can be assessed using smoke, or by driving a vehicle along a dusty track. Concentration of smoke or dust within a thin layer may indicate the presence of a surface temperature inversion.

2.6. Spray application technology

2.6.1. Droplet generation

In order to create a droplet, which carries and transports the active constituent to the target, energy must be expended on the bulk spray solution. This can be done by five alternative methods:

1 *Pressure* – by forcing the spray liquid under pressure through a small, specially designed orifice. Such devices are normally referred to as hydraulic nozzles and they are available in a number of different types designed for different purposes. The most common types of hydraulic nozzles used for spraying are flat fan, hollow or full cone, or deflector nozzles. CP™ nozzles, a recent introduction to aerial spraying, are an example of a deflector nozzle. Air may also be forcefully or passively introduced into the nozzle chamber. These are known as air induction or twin fluid nozzles.

2 *Centrifugal* – by subjecting the liquid to centrifugal energy. By precisely feeding liquid onto a spinning disc, it is possible to generate droplets at the edge of the disc as liquid is spun off into the surrounding air. Droplet size is influenced by the rotational speed of the disc, the nozzle design and liquid flowrate. Spinning cages, as used in Micronair™ units, are an extension of this principle. Spinning discs are normally referred to as controlled droplet applicators (CDA) as they generally produce a narrower range of droplet sizes than hydraulic nozzles.

3 *Air shear* – by subjecting liquid to high velocity air, droplets can be generated as the liquid is torn into small particles by the mechanical impact of the moving air stream. Systems employing this principle are normally referred to as air shear nozzles.

4 *Vibration* – by utilising vibrational energy. These include ultrasonic nozzles, vibrating tips, piezoelectric crystal devices, etc. They are primarily for experimental purposes and are not available for commercial spraying

5 *Electrostatic* – by utilising electrical charge either via induction, corona discharge of an ionised field. A few electrostatic nozzles are available commercially.

The energy is expended to do work against surface tension and viscous forces, and to increase the surface area of the spray liquid by forming droplets. There are three basic modes of droplet formation:

1 *Sheet break-up* – the main mode associated with hydraulic nozzles. Break-up takes place either at the edge of a sheet (rim disintegration) or within the sheet (perforation). The range of droplet sizes produced is usually broad.

2 *Ligament break-up* – the main mode associated with spinning disc nozzles. The range of droplet sizes produced under the right conditions can be narrow.

3 *Direct droplet formation* – obtainable with spinning discs at very low flow rates. The range of droplet sizes produced can be extremely narrow or monosized.

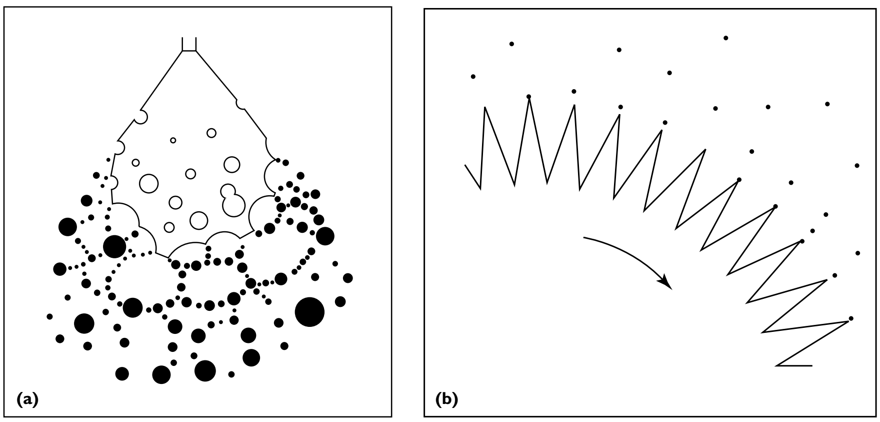


Figure 11. Droplet formation from (a) a hydraulic nozzle and (b) a centrifugal energy spinning disc.

2.6.2. Droplet size

Droplets used in spraying are small! Applicators often refer to droplets of 10, 100 or 500 µm in size, forgetting that 10 and even 100 µm droplets may not be visible to the naked eye. As an example, the full stop at the end of this sentence is approximately 300 µm in diameter. This size is considered a large droplet in spray application technology. A micrometre (µm) is equivalent to 1/1000 of a millimetre (mm) and thus a 500 µm droplet is half a millimetre (0.5 mm) in diameter. Spray equipment can be selected or adjusted to produce droplets within a desired size range that is best suited to particular targets.

Droplet size is a highly significant spray parameter largely determined by equipment settings and product formulation. The larger the droplet diameter, the less a spray is susceptible to drift. Once a droplet is generated, it must be transferred through the air to the target. The size of the droplet, its initial speed of travel, rates of evaporation and meteorological conditions all influence the movement of a droplet through the air. Unfortunately, no practical spray nozzle produces droplets that are all the same size. All commercial nozzles generate a range of droplet sizes.

Work overseas has sought to establish an international standard for defining spray quality. The British Crop Protection Council (BCPC) nozzle classification scheme was devised during the mid 1980s as a means of standardising the relationship between a variety of measurement systems and describing the entire droplet spectrum generated by a spray nozzle. The scheme was developed in the United Kingdom by a committee of government, academic and industry personnel. Five categories of spray quality were devised, very fine, fine, medium, coarse and very coarse. The scheme was originally developed for defining ground hydraulic application nozzles; however, other nozzle types are now being encompassed by the scheme.

The categories are defined using four reference sprays (defined nozzles and pressures, Table 1 and Figure 12). Categories were originally defined by the mid-point of each spray's spectra curve. However, the categories are now being defined using the boundary reference curve sprays. Reference nozzle sets are available from several sources worldwide to assist laboratories to establish the reference boundary curves.

Recently, in an effort to harmonise nozzle classification schemes between the USA and Europe, the Power Machinery PM41 committee of the American Society of Agricultural Engineers (ASAE) developed a standard (S572) based upon the BCPC classification system. This standard includes the five basic BCPC size classes plus an additional Extra Coarse class to represent sprays that contain very large droplets. Tap water is now used as the test substance for the measurement of reference curves.

BCPC Boundary Category	Nozzle size	Liquid pressure (kPa)	Liquid flowrate (L/min)
Very Fine/Fine (VF/F)	11001	450	4.820
Fine/Medium (F/M)	11003	300	1.200
Medium/Coarse (M/C)	11006	200	1.940
Coarse/Very Coarse (C/VC)	8008	250	2.150
ASAE S572 Extra Coarse	6510	200	

Table 1. BCPC reference nozzles and settings (from Hewitt 1999).

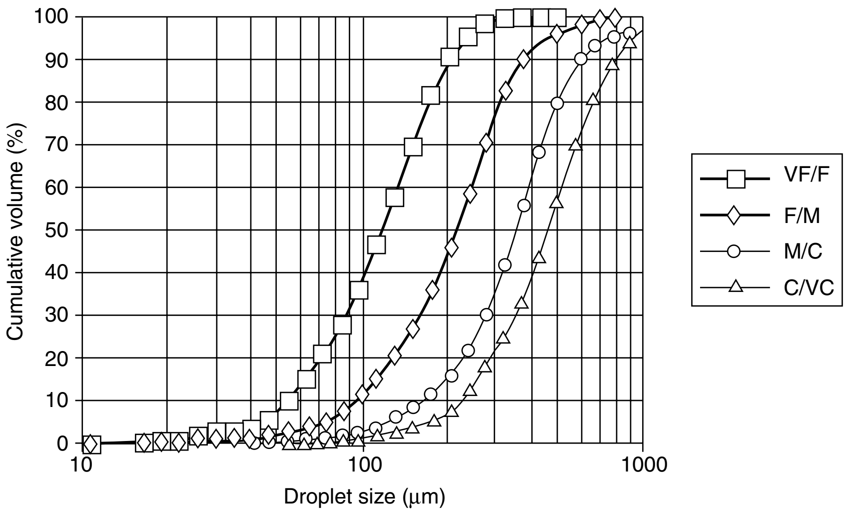


Figure 12. A BCPC droplet size reference curve.

Such classification systems enable regulators, researchers, applicators and growers to standardise the description of nozzle systems and thus spray quality. Spray quality is one of the best ways an agrochemical company or regulator can communicate via the label to the farmer. The classification system, if fully adopted by the Australian industry, will allow manufacturers and regulators not only to describe spray quality and thus nozzle systems for particular uses, but also to provide a mechanism for defining buffer distances for pesticide drift control. The system, based upon spray quality rather than nozzle type, allows applicators some flexibility to select spray configurations best suited for their local conditions.

The nozzle classification scheme is now also being used internationally to describe spray quality in spray drift simulation models such as AgDRIFT™. Droplet size is the primary factor governing the distance a pesticide droplet will drift after release from a sprayer. Droplet diameter determines the speed at which it falls to the ground when released into (still) air – the terminal or sedimentation velocity. A 250 µm droplet has a sedimentation velocity of approximately 1 m/s and so will fall to the ground from most sprayers within a few seconds after release. A 100 µm droplet, however, has a sedimentation velocity of 0.25 m/s and can be subject to significant drift. Such droplets can impact onto flat surfaces several hundred metres downwind of the target area, depending upon release height and wind speed. A 10 µm droplet, however, has a sedimentation velocity of 0.003 m/s and may be considered as essentially airborne. A few 10 µm or aerosol-sized droplets may eventually deposit upon fine surfaces such as hairs, but most end up as residual particles or gas and are lost to the atmosphere. Adequate control of droplet size is therefore essential if spray drift is to be effectively managed.

As previously discussed, no practical spray nozzle system used in agriculture produces droplets that are all the same size. All commercial nozzles generate a range of droplet sizes. A summary of the main values that are used to describe the droplet spectra produced by different nozzles is presented in Table 2. The Volume Median Diameter (VMD) is the most commonly used descriptor of droplet diameter. The VMD divides the droplet spectrum into two equal parts. One half of the total volume is made up of droplets larger than the VMD and the other half is made up of droplets smaller than the VMD. Two different nozzles may produce the same VMD but may actually produce a quite different droplet spectrum. One nozzle may produce droplets that all fall in a very narrow band around the VMD, while the other nozzle may produce a very large range of droplet sizes. Similarly, the Number Median Diameter (NMD) divides the droplet sample in half by number. The NMD is always less than the VMD.

The use of laser droplet sizing instrumentation enables droplets to be sized in flight shortly after release from a nozzle. These non-intrusive techniques can provide an accurate indication of the complete droplet size distribution, or spectra, emitted from a nozzle. Other methods, which rely on post application collection, such as spray sensitive cards and papers, can generate errors due to sampling and collection bias (see Section 2.6.5.). Three main methods exist that utilise lasers to measure droplets:

1 Malvern 2600 Laser Diffraction Analyser

2 Knollenberg Particle Measuring System (PMS) Laser Shaddowing

3 Laser Doppler Anemometry (LDA)

The Malvern 2600 Laser Diffraction Analyser operates by directing a laser beam unobtrusively through a spray cloud. Spray droplets diffract the light through different angles according to droplet size. The diffracted light is focused onto a semicircular detector. With the use of calibrated algorithms based upon Mie Diffraction Theory, the droplet spectrum (by volume) for an entire spray cloud can be computed. This is known as a spacial sampling technique. By adjusting the lens system on a Malvern 2600 analyser, the diameter of droplets between 0.5 μm and 1880 μm can be measured in six operating ranges. The Knollenberg PMS analyser works in a similar way except that the shadow image from a droplet is focused onto a linear photodiode array. The image from each droplet as it passes through the laser beam is recorded. This is known as a temporal sampling technique.

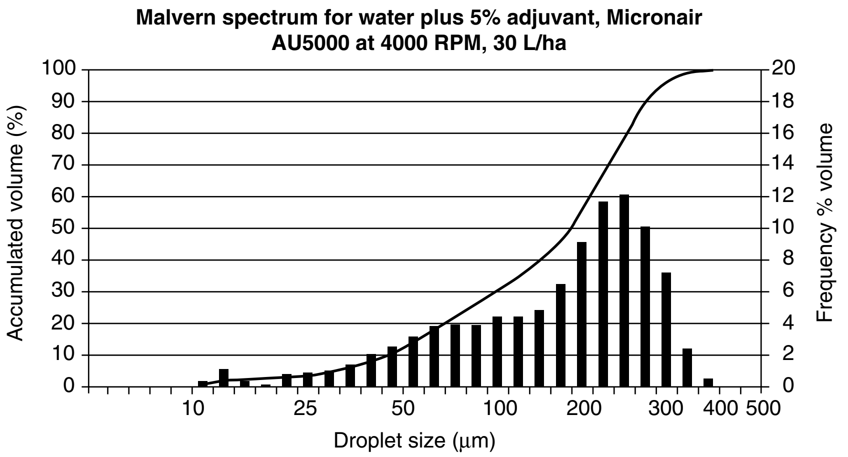


Figure 13. Typical droplet spectra measured using a Malvern Laser Diffraction Analyser.

Droplet spectra are normally represented by a frequency histogram or an accumulated volume curve. The accumulated volume curve indicates the percentage volume of the spray less than a given size and can be used to calculate VMD. Figure 13 shows a typical droplet size distribution for a Micronair™ rotary cage nozzle determined in the laboratory by the University of Queensland. The VMD of the spray is determined by the droplet size at which the accumulated volume curve crosses the 50% line. In this case, the spray had a VMD of approximately 180 µm.

Parameter	Definition	Units	Comments
VMD or D[v,0.5]	**Volume Median Diameter** Diameter that contains 50% of volume in drops of smaller size.	(µm)	Most commonly used value for describing droplet size.
D[v,0.1]	Diameter that contains 10% of volume in drops of smaller size.	(µm)	Useful indication of small droplets, which are prone to drift.
D[v,0.9]	Diameter that contains 90% of volume in drops of smaller size.	(µm)	Useful indication of large droplets, which can be wasteful of chemical.
Relative Span	Measure of the width of the volume distribution relative to the volume median diameter VMD $= \frac{D[v,0.9] - D[v,0.1]}{VMD}$	**	The lower the span, the more uniform the droplet spectra. For monosized droplets, span = 0
NMD	**Number Median Diameter** Diameter that contains 50% of number in drops of smaller size.	(µm)	NMD is always less than VMD except for monosized droplets, where NMD = VMD
R	Measure of the width of the volume distribution = VMD/NMD	**	The smaller the value of R the more uniform the droplet spectra. For monosized droplets, R = 1

* µm or micrometre or microns = 1/1000 mm
** dimensionless

Table 2. Summary of some technical definitions used for describing droplet size.

2.6.3. Droplet transport

Once a droplet is formed, it is transferred through the air to the target. The movement of a droplet through the air is influenced initially by its release speed. Most ground application equipment releases droplets in close proximity to a canopy target, thus initial energy imparted by nozzles and the use of high-speed airflows can influence the transmission of droplets over short ranges. With aerial spraying, however, this motion soon decays and droplets assume the speed of the air around them, very quickly moving entirely under the influence of gravity and the local prevailing wind and turbulence. Large droplets, because of their greater mass and fall speed, tend to quickly deposit on horizontal surfaces such as the ground or broadleaf weeds close to their point of release. Small droplets, however, fall slowly and are subject to movement away from the treatment area by the prevailing wind.

Vertical and horizontal air movement must be appreciated to understand fully the droplet transport process. When droplets are large (eg. >300 µm) their passage towards the ground from spray equipment is largely influenced by gravitational forces. In other words, the droplets tend to impact on the ground largely unaffected by air currents, unless the wind velocities are very large. However, many droplets produced by spray equipment are smaller than 300 µm. As droplets decrease in size, their movement becomes increasingly controlled by the movement of air around them. Consequently, it is important to understand the way in which air is moving above a crop in order to spray effectively and control the off-target movement of material.

The main weather conditions influencing droplet transmission are wind speed and turbulence/stability (see Section 2.5.). Importantly, droplets are always transported in the direction of the flow of air. Temperature and relative humidity also influence the transport of droplets, in that they can change the inflight diameter of water droplets through evaporation.

A simple model known as the Porton model can be used to predict downwind distances travelled by droplets, as long as the effects of turbulence and evaporation are ignored. Table 3 illustrates the *theoretical* downwind distance droplets would be transported if released 3 metres above a crop in a steady cross-wind blowing at 1 metre per second. In practice, effects such as turbulence and droplet evaporation have a major influence on downwind deposition and Table 3 should therefore not be used to predict safe downwind buffer areas.

Droplet diameter (µm)	**Terminal velocity (m/s)**	**Time to fall 3 m**	**Downwind displacement in 1 m/s wind (m)**
1	0.000 03	28.1 h	10 000
10	0.003	16.9 min	1000
20	0.012	4.2 min	250
50	0.075	40.5 sec	40
100	0.28	10.9 sec	10.7
200	0.72	4.2 sec	4.2
500	2.14	1.7 sec	1.4
1000	5.0	0.8 sec	0.6

Table 3. Porton model predicted distances for off-target transport. This model should not be used for predicting the transport of small droplets, as their motion is dominated by turbulence rather than gravity.

2.6.4. Turbulence

Atmospheric turbulence can develop over a crop as a result of the thermal (upward) movement of warm air or the mechanical movement of wind across the ground. A wind or breeze travelling close to the surface of the earth rarely has a smooth flow. Instead, the atmosphere is characterised by the turbulent motion of air produced, in part, by the movement of air layers against each other and by frictional losses of energy at the earth's surface. The extent of this turbulence is also determined by the 'roughness' of the surface. For example, a stand of trees or a tall crop would generate greater turbulence for a given wind speed than an area of mown grass. Turbulence intensity (i) may be defined as U*/U, where U* is the root mean square of the vertical motion of air and U is the mean wind speed.

Turbulence intensity controls the dispersion rate of the spray cloud (Figure 14). It is affected by a combination of lapse dependent stability and mechanical turbulence generated by ground obstacles. Values are approximately 0.1 over most agricultural crops in neutral conditions, but can be less than 0.05 over bare ground in stable conditions and may rise to 0.15 or 0.2 over forests in unstable conditions (Pasquill *et al* 1983). With increasing turbulence intensity, the peak deposit is higher and closer to the source. Far downwind deposition levels, however, are higher at low turbulence intensities. This highlights the dangers of spraying with small droplets in stable conditions. Turbulence, however, has little effect on large droplet deposition.

The distance to peak deposition may be roughly correlated with HU/U* for small droplets and HU/Vs for large droplets, where H is the release height of the spray, U is the mean wind speed and Vs is the sedimentation velocity of the droplet. Table 4 demonstrates the importance of turbulence in the transmission of droplets, particularly small droplets. If the effect of turbulence is taken into account, as described by a Gaussian settling plume model (eg. Bache and Sayer 1975), the dispersive nature of turbulent (mechanically generated) airflow can be shown to bring the peak deposit of sprays down to the ground very rapidly. Unfortunately, the expansive nature of turbulent flow also tends to disperse a low concentration of very small droplets into the atmosphere and at extended distances downwind.

Droplet diameter (μm)	Wind speed U = 1 m/s		Wind speed U = 4 m/s	
	(S)	(S+T)	(S)	(S+T)
10	166.66 m	3.49 m	666.00 m	3.52 m
25	26.31 m	3.31 m	105.00 m	3.47 m
50	6.94 m	2.74 m	27.77 m	3.31 m
100	2.00 m	1.59 m	8.00 m	2.84 m
150	1.09 m	1.00 m	4.35 m	2.38 m
200	0.71 m	0.69 m	2.86 m	1.97 m
300	0.43 m	0.43 m	1.74 m	1.45 m
500	0.25 m	0.25 m	1.00 m	0.93 m
1000	0.13 m	0.14 m	0.52 m	0.51 m

Table 4. Comparison between drift models. The numbers indicate the distance to peak deposition for the sedimentation only (S) (Porton model) and the sedimentation plus turbulence (S+T) (Bache and Sayer model).

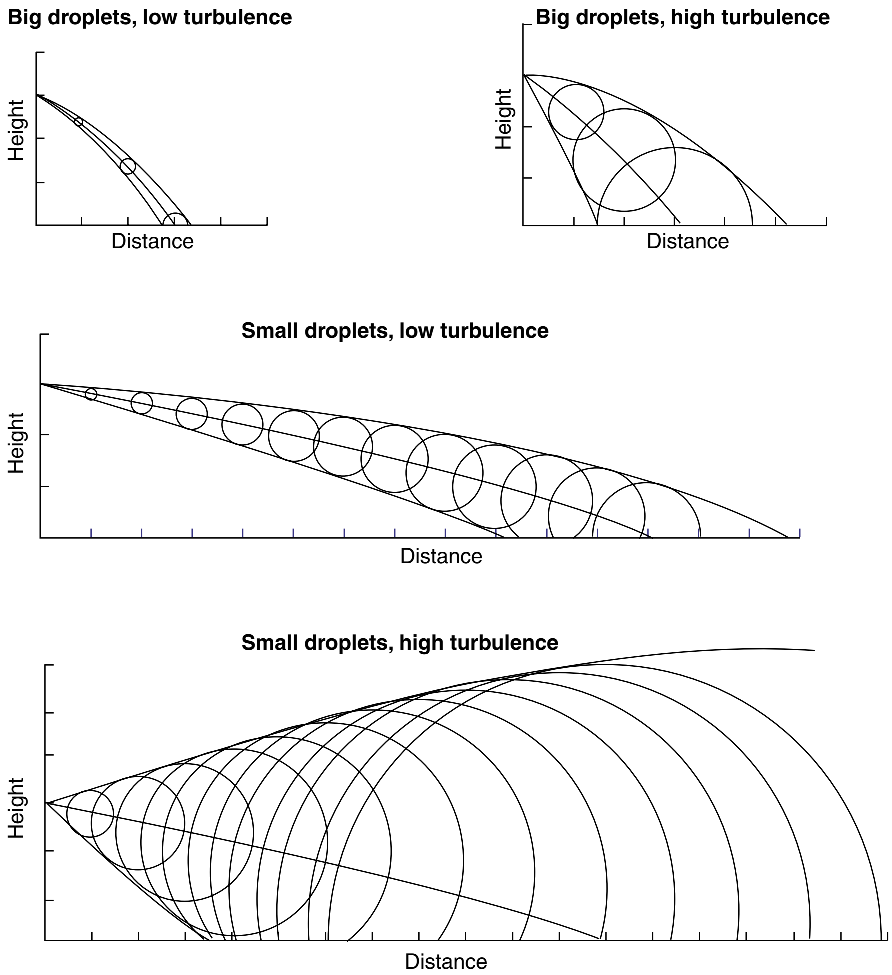


Figure 14. Effect of droplet size and turbulence on cloud dispersal and ground deposition (after Spillman 1982).

2.6.5. Droplet impaction

For spraying to be effective, droplets must be deposited on the plant or insect target. Target size, shape and orientation, droplet velocity and size, and weather conditions all influence the ability of the droplet to land on the target. Objects such as branches and leaves on crops cause air to be deflected around them. A small droplet tends to follow the path of air that surrounds it, whereas a larger droplet has sufficient momentum to deviate from this air and impact upon the target. The smaller the catching surface, the less the air deviates around the object and the greater the chance of intercepting small droplets. Small hairs on insects and stems or needle-like leaves on trees are, for example, more efficient at removing small droplets than broad relatively smooth eucalyptus leaves (Figure 15).

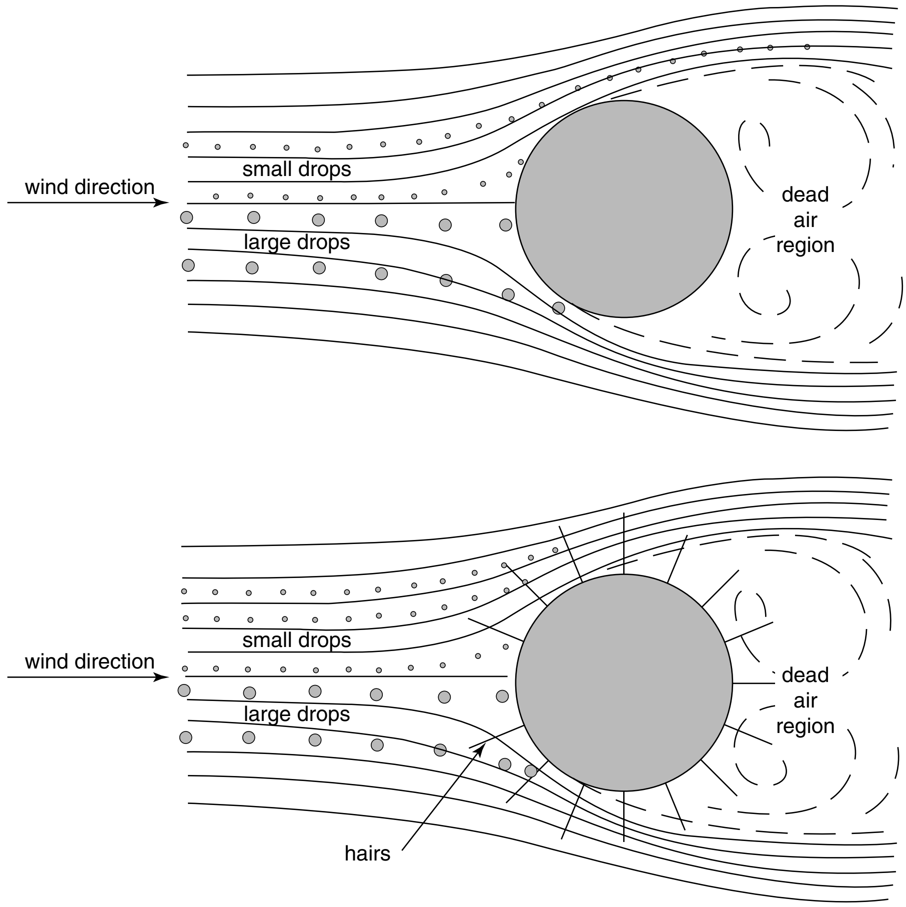


Figure 15. Effect of target characteristics on droplet capture.

The ratio of the number of droplets striking the object to the number that would strike if the air were not deflected is called Collection Efficiency (E). The greater the value of E, the greater the deposition on the target. In general, E increases as the relative velocity between the droplet and the target increases, as the diameter or width of the target decreases and as the droplet size increases.

2.6.6. Ground (boom sprayer) application

Boom sprayers are the most common means of applying farm chemicals to field and vegetable crops. While there are many parts to a boom sprayer, the primary component that directly influences spray drift is the spray nozzle. Secondary structures such as shields are sometimes used to mitigate spray drift by redirecting the movement of the air and droplets around a crop. Agricultural nozzles generally fit into one of five categories: hydraulic, controlled droplet applicators (CDA), air shear, twin fluid and electrostatic.

Hydraulic nozzles are the most common type of nozzle found in ground application equipment. A hydraulic nozzle has to meter liquid flow, generate a specified droplet size range and direct the spray in a desired direction and pattern. While their limitations (primarily the wide range of droplet sizes that are produced) have long been recognised, their simplicity, robustness and cost have led to their widespread adoption by Australian growers.

Hydraulic nozzles operate by forcing a spray liquid under pressure through a small specially designed orifice. A large number of different nozzle types are available for a wide range of applications. Hollow cone and flat fan nozzles are the most common types of hydraulic nozzle used for spraying in agriculture. Flat fan nozzles have traditionally been used for herbicide application and applying pesticides to horizontal and ground surfaces, and hollow cones for insecticide and fungicide application. Hollow cone nozzles are generally operated at higher pressures and may produce smaller droplets than flat fan nozzles, which are more appropriate for foliage spraying. There has been a general trend away from hollow cone to flat fan nozzles for many types of pesticide application because flat fan nozzles are capable of applying more uniform deposits over the area to be treated.

Other types of hydraulic nozzles include solid cone, even fan and anvil (sometimes referred to as flood jet or deflector) nozzles. There has been an expansion in the range of hydraulic nozzles available in recent years, with most manufacturers now producing a type of 'low drift' nozzle. Most low drift nozzles utilise a secondary chamber to trap and recirculate fine droplets generated by the nozzle.

Depending on travel speed and nozzle type, orifice size and boom layout, application volumes can vary from 30 L/ha to over 1000 L/ha. Application rates also vary depending on crop type. Broad-acre systems such as grains and cotton typically use application volumes between 50 and 100 L/ha. Horticultural operations typically apply pesticides between 200 and 500 L/ha, with some products applied at higher rates.

2.6.6.1. Rotary

Rotary nozzles such as controlled droplet applicators (CDA) are fitted to a range of hand-held equipment, some boom sprayers and aircraft. Controlled droplet nozzles subject the liquid to centrifugal energy. By precisely feeding liquid onto a spinning disc it is possible to generate droplets at the edge of the disc as liquid is spun off into the surrounding space (Figure 11). Droplet size is controlled by the rotational speed of the disc, the nozzle design and liquid flow rate. Finer droplet sizes are normally produced as more energy is put into the system and disc rotational speeds are increased. Spinning cages as used in Micronair™ nozzles are an extension of this principle. Spinning discs tend to produce a narrower range of droplet sizes than hydraulic nozzles. CDA systems typically produce fine droplets, but large droplets can be produced by changing disc design and reducing disc rotational speed. Low application rates are normally used with CDA equipment (3 to 100 L/ha).

2.6.6.2. Twin fluid

By feeding liquid into a high velocity jet of air, droplets can be generated as the liquid is torn into small particles by the mechanical impact of the moving air streams. Nozzles that use this principle are termed air shear nozzles. By adjusting the airspeed and liquid flow rate, droplet size can be altered. With air shear nozzles, the energy imparted by the air is used to produce the droplets. This technology should not be confused with air-assisted systems that use hydraulic nozzles to produce the droplets and then introduces air to control subsequent droplet movement.

Air induction and pressurised air nozzles introduce both air and liquid either inside or outside the nozzle. Air may be forced into the nozzle by means of a compressor (eg. Airtec, Optispray and Airjet) or self-aspirated (eg. TurboDrop® and Injet®). It has been shown that air inclusions may be present inside the droplets produced by these nozzle systems. Debate remains amongst researchers as to how the droplet size generated by such systems can be accurately measured. It has been demonstrated that drift can be reduced by the use of such nozzles (Matthews 1992).

2.6.6.3. Electrostatic

Electrostatic nozzles have received much attention (Matthews 1992). A few commercial units have been marketed but have not received widespread use. Theory suggests that charged small droplets can be attracted to a plant surface and this can lead to a reduction in spray drift. Only small droplets can be charged sufficiently to be attracted to nearby earthed objects.

2.6.6.4. Wiper applicators

Wiper applicators are used to apply herbicides directly to weeds by physical contact with a herbicide-soaked sponge or wick. This can be a very effective method where there is a physical separation in height between the weed and desirable crop species. As no droplets are produced, drift from these applications is very low.

2.6.6.5. Shields and air assistance

Small droplets quickly lose momentum imparted by a nozzle system and tend to quickly assume the speed and direction of ambient airflow. If the air movement around the sprayer can be altered so that it is directed towards the target, it is possible to reduce drift as well as increasing deposition on the target. This is the basic principle behind the design of air-assisted sprayers (eg. Hardi twin) and air deflectors along the boom (eg. bluff plate sprayer). Mechanical shields, as well as deflecting air, can also provide a barrier that physically intercepts the drifting droplets.

SpraySearch Victoria (Daratech Pty Ltd) on behalf of the Grains Research and Development Corporation (GRDC) conducted both field trial and wind tunnel studies at Werribee, Victoria, in the mid 1990s to compare the drift performance of a range of spray systems (Young 1996, French *et al* 1993). Field trials in Horsham were also carried out.

They compared the following systems:

1 Standard boom fitted with flat fan nozzles

2 Spraying Systems drift guard nozzles
3 Hardi twin
4 Airtec twin fluid nozzles
5 Flexicoil wind shield
6 Bluff plate sprayer
7 Spray management valve fitted with extended range nozzle
8 Hardi stream
9 Spray Smart twin fluid nozzle
10 Brandt wind cones
11 Rogers shielded boom

They found that all the sprayers reduced spray drift when compared to the standard boom. The wind tunnel studies indicated that in a 15 and 30 km/h airflow, all sprayers evaluated generated 20–50% less drift than the standard boom.

2.6.7. Orchard spraying

Where large, dense tree crops have to be sprayed, high volume air-assisted 'airblast' sprayers are used. In Australia, a wide range of custom-built and commercial orchard sprayers are used for crop protection strategies in vine crops and evergreen and deciduous tree crops (Battaglia 1999, Battaglia and Harden 1997). A range of drift management techniques exist that dictate the type of sprayer to be used and how it should be operated.

Most sprayers use air assistance to convey droplets to the target zone within the tree canopy. Some sprayer types use high velocity air to produce and transport droplets to the target. The biological efficiency and off-target losses generated by a sprayer are determined by a number of variables. Some of the features that are used to distinguish between sprayers are:

- *Sprayer configurations.* There are many configurations of sprayer used for pesticide application in orchards. These include low profile, tower, airblast, combination, multi-head spray systems and ducted conveyors. The sprayers may also be single- or double-sided (Battaglia 1999).
- *Nozzle types used and pressure.* A wide range of nozzles are used on orchard spray equipment. Ceramic hollow cone and solid cone (operational pressure range 5–20 bar) are the most common form of hydraulic nozzle. Air shear technology (200–350 km/h at the nozzle outlet) and CDA systems (X1, Spanspray, Micronair™) are also used.
- *Air volumes.* A wide range of fan types, sizes and number of fans are used on orchard sprayers. The location of the fan in relation to tree canopy and the sprayer can also influence airflow. Air calibration and configuration have a large influence on droplet movement and canopy penetration. Australian airblast equipment is normally calibrated to deliver between 15,000 m^3/hr and 150,000 m^3/hr. Air volume should normally be matched to tree volume. If air

volume is too low, droplets may fail to sufficiently penetrate the tree, so coverage and efficacy is reduced. If air volume is too great, droplets tend to pass though foliage, thereby increasing the drift potential.

- *Water volumes applied.* Carrier water volumes vary greatly and depend upon equipment, industry, location and pests targeted. Volumes may range from 150 L/ha to 10,000 L/ha.
- *Row/tree spacing.* Row and tree spacing depend on the crop. There is a trend in some industries for high density planting of trees – that is, closer rows and closer tree spacing within rows. Row spacings vary from 2.5 m to 12 m and tree spacings 1.5 m to 10 m+.
- *Travel speeds.* These vary considerably, ranging from 1.5 km/h to 10 km/h. Ground speed does not usually have a large impact on spray drift.
- *Tree configurations.* Allowing trees to form hedges is becoming common practice in many industries. This has benefits in terms of spray drift management as trees on the outer edge of a plantation can be used as vegetative barriers. However, the reduction in spray coverage on plantation boundaries can cause efficacy and production problems.

2.6.8. Aerial spraying

There are currently about 300 aircraft registered in Australia for the application of pesticides. These specialist aircraft, flown by pilots from about 100 aerial application companies, apply pesticides and fertilisers to about 10 million hectares annually (under average to good seasonal conditions). There are approximately 1100 pesticides registered for agricultural purposes in Australia, of which approximately 370 are registered for aerial application. Typically, individual jobs range in size from 5 to 500 hectares with some 100,000 separate application missions normally carried out per annum.

1	Aircraft can be used over wet/irrigated areas, impassable to a wheeled vehicle.
2	Being clear of the ground, soil impaction and wheel marks are eliminated.
3	Aircraft are faster and more fuel-efficient.
4	Airborne application allows timely treatment of pests and diseases.
5	Better coverage and penetration of a crop can be achieved in some circumstances.
6	Grower labour is reduced.
7	Aircraft can overcome limitations when crop height acts against ground-based equipment.
8	A grower can have the additional facility of conferring application to skilled professional users with correctly calibrated application equipment and dedicated pesticide handling systems.

Table 5a. Some advantages of using agricultural aircraft for pesticide application.

The case for and against using agricultural aircraft is summarised in Tables 5a and 5b. Their use in post-war agriculture has developed largely as a result of the greater speed, better timing and efficiency of application offered by the airborne platform. Crossing the ground at about 200 km/h, aircraft are able to apply agricultural products rapidly over large areas within narrow optimum application windows. When crop height and irrigated areas restrict the passage of ground-based spray rigs, aircraft are able to place pesticides strategically on crops in response to economic thresholds without contributing to soil compaction and structural breakdown. Australia leads the world in some aspects of ultra low volume (ULV) and large droplet placement (LDP) technology and uses some of the largest, safest and most powerful specialist aircraft available.

1	Compared to some ground equipment, aircraft release sprays from greater heights. This may increase drift potential.
2	Low flying (contact with the ground) poses significant risks for the pilots of agricultural aircraft.
3	Generally, more expensive than ground-based spraying.
4	Aircraft operations should be confined to optimum 'application windows' which may sometimes be short, (eg. 2–3 hours after sunrise).
5	Small cropping areas and those surrounded by obstructions or susceptible areas are not able to be treated.
6	Aircraft (helicopters and aeroplanes) are visible and audible – they attract attention and may cause noise pollution.
7	Under/over-dosing more likely than with ground-based application equipment.

Table 5b. Some disadvantages of using agricultural aircraft for pesticide application.

2.6.9. Wingtip vortices and boom length

Since the lift generated by a wing produces an area of high pressure upon the lower surface of the wing and an area of low pressure upon the upper surface of the wing, there is a tendency for air to spill over at the tips in the direction from high to low pressure. This causes wing-tip vortices to be formed, which give rise to vortex or lift-dependent drag. It is these vortices, necessary for lift, that give rise to spreading of the spray and the subsequent swath width of the aircraft.

However, if the boom length is as long as the wingspan of the aircraft, then excessive amounts of spray (particularly small droplets) can become incorporated in the vortices and spray can be released well above the height of the aircraft. To minimise incorporation of spray into wingtip vortices, boom lengths are usually maintained less than about 65–75% of the wingspan of an agricultural aircraft (Figure 16).

Vortex strength is increased when an aircraft is flown slower and heavier and when the lift generated by a wing is increased – for example when an aircraft pulls up out of a field. For this reason, spray systems should not be operated until an aircraft is level over a crop and should be turned off before an aircraft pulls up out of a treatment area.

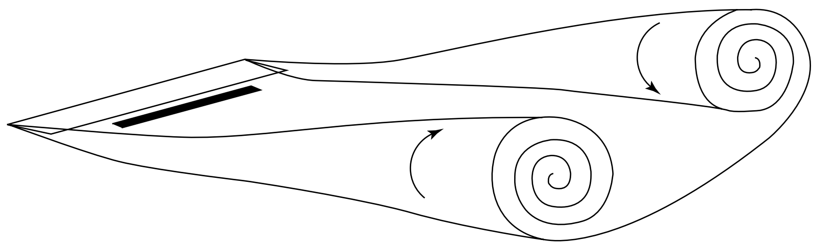


Figure 16. Wing-tip vortices; boom length should not exceed 65% of the wingspan of the aircraft.

2.6.10. Droplet size

A world-class pesticide wind tunnel research facility was commissioned at the University of Queensland during 2000/01. This facility is able to determine the droplet spectra emitted by nozzle systems in airspeeds up to 140 knots. Such facilities are able to generate the type of data shown in Figures 17 and 18. The graph in Figure 17 demonstrates that a decrease in droplet size occurs when a Micronair™ AU5000 nozzle is operated at lower rotational speeds and demonstrates the importance of operating such equipment at correct settings. In this example, endosulfan formulations were tested over the range of RPM/flowrate conditions. A maximum VMD of approximately 170 µm was generated. Importantly, the data also shows that both water-based emulsifiable concentrates (EC) and oil-based ultra low volume (ULV) formulations generated similar VMDs. Figure 17 also shows the effect of increasing airspeed on the production of smaller droplets. Given the ease and accuracy with which such data can now be obtained, Micronair™ units should be operated specifically within nominated rotational speed windows and the use of onboard transducers for monitoring rotational speed should be encouraged.

Compared with the AU5000, significantly greater droplet sizes (VMD) can be obtained by using certain large orifice hydraulic nozzles. Work conducted by SpraySearch Victoria (Figure 18) shows that VMD values greater than 200 µm were obtained at lower operational airspeeds. To obtain larger droplets, nozzles should be angled back at 180° to the local airflow so that the orifice tip faces the rear of the aircraft.

It should be noted that the droplet size generated by some aircraft in flight can be marginally increased by *increasing* hydraulic pressure. When a nozzle is pointing rearwards, an increase in hydraulic pressure can effectively decrease the relative velocity between the spray liquid and local air velocity. Agricultural pilots should consult the aircraft nozzle manufacturer's information.

When larger droplets are generated, higher volumes of carrier (usually 30 L/ha+) should normally be used to ensure that sufficient coverage of targets is maintained.

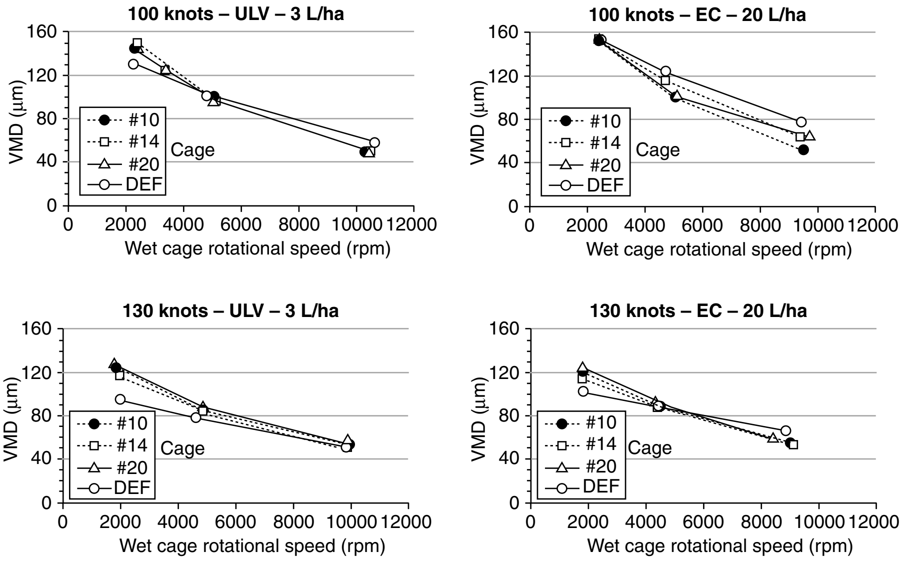


Figure 17. Droplet size (Volume Median Diameter) generated by a Micronair™ AU5000 rotary cage nozzle applying two formulations of endosulfan (ULV and EC) at two airspeeds (100 and 130 knots).

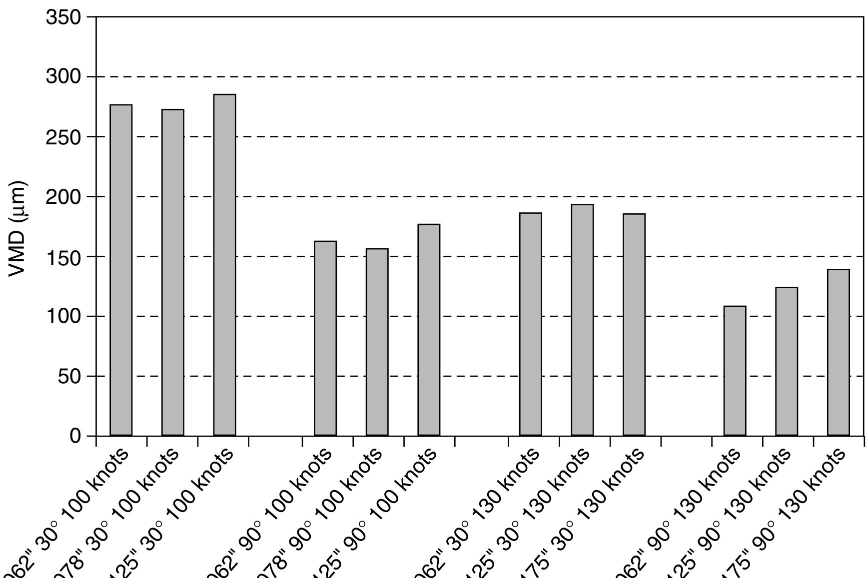


Figure 18. Volume Median Diameter (VMD) generated by the CP™ hydraulic nozzle spraying endosulfan EC at airspeeds of 100 and 130 knots, and at angles of the nozzle deflector plate to the air stream of 30° and 90°.

2.6.11. Effect of airspeed

Spray released from a moving aircraft is subject to an airblast that causes larger droplets in the spray to break up and produce fine droplets, thus increasing the drift potential of the spray. The effect of airspeed on spray break-up becomes very important above about 115 knots. Tests carried out in wind tunnels show that increasing airspeed from 100 knots to 140 knots can effectively quadruple the driftable fraction of the spray, ie. the percent volume less than 100 µm increased from approximately 5% to greater than 20% of the spray (Figure 19).

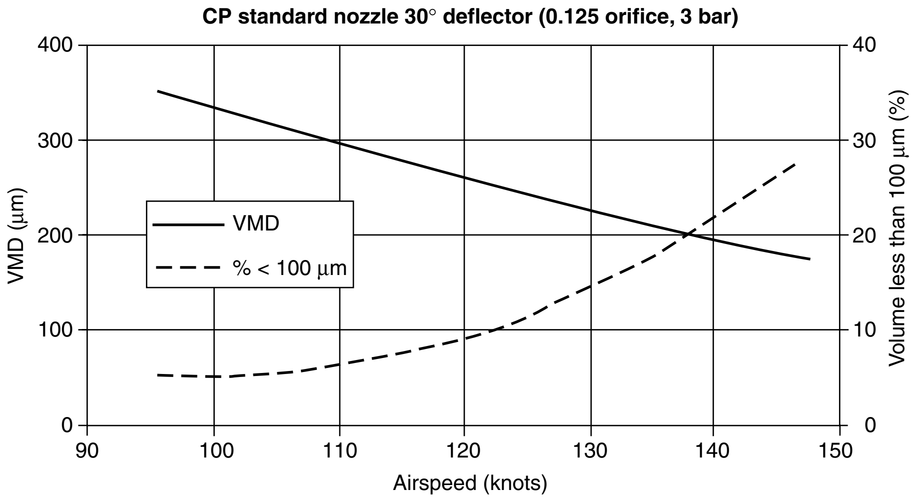


Figure 19. Effect of airspeed on droplet size (after Kirk 1998).

2.6.12. Field studies

A comprehensive series of field studies was undertaken in Australia as part of the LWWRDC/CRDC/MDBC national program (Woods *et al* 2000). The aerial transport of pesticides was monitored following commercial application on cotton farms and from a series of monitored experimental studies. A summary of many of these tests is summarised in Figure 20.

With ULV application, approximately 14% of the amount applied to a 500 m wide field was found to move across the downwind edge of a field (Woods 1998a). The comprehensive monitoring program undertaken to quantify this 'tail' showed that both airborne fractions of endosulfan and downwind deposit levels could be reduced by increasing droplet size and using large droplet low volume (LV) application techniques. This technique, however, also caused a higher fraction of the spray to be deposited at soil level beneath the crop canopy.

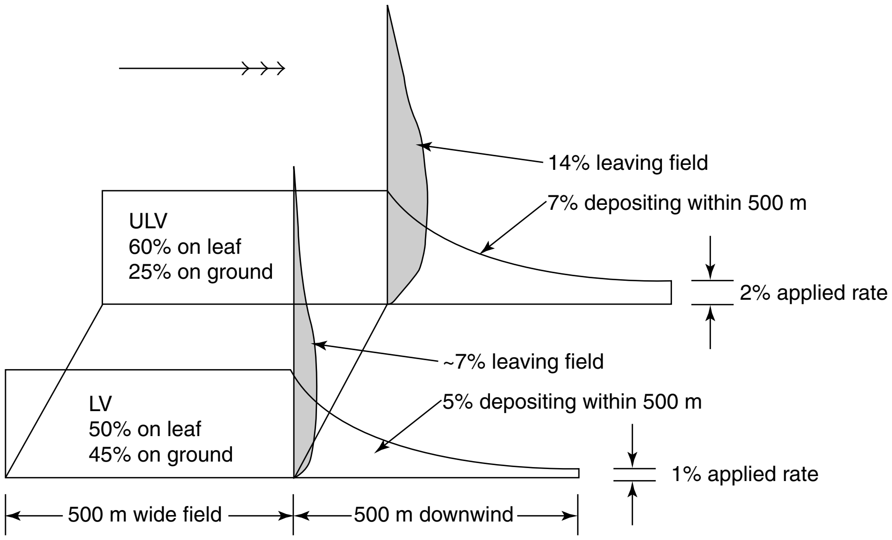


Figure 20. Summary of endosulfan transport characteristics from the LWRRDC program.

2.6.13. Spray drift management

By adopting a range of integrated strategies, off-target downwind transport of pesticide can be appreciably reduced. Field experiments have shown that by selecting appropriate wind vectors, adopting large droplet placement (LDP) application techniques and creating in-crop buffer distances on the downwind sides of sprayed areas, the off-target droplet movement of sprays can be reduced. Such technologies benefit from being incorporated into holistic best management practices that encourage awareness zone assessment and the selection of the most appropriate case-specific mitigating strategies.

If the BCPC/ASAE nozzle classification standards are fully adopted by Australia, it is possible that downwind buffer distances could be defined in terms of spray quality.

2.6.14. Ultra low volume (ULV) spraying

Defined as small droplets (<100 µm VMD) applied at rates of less than 5 L/ha.

ULV pesticides formulated in low-volatile oil-based carriers are applied ‘straight from the can’ at total application rates of 2–5 L/ha. This low rate of carrier is achieved by generating small droplets (say 50–100 µm VMD). Such droplet sizes allow large numbers of droplets to be generated, thereby compensating for the low volume of carrier. The technology can be highly efficient and lead to decreased application costs as a result of fewer take-offs and landings and less ferry time being required per litre volume applied. However, ULV application can have a significantly higher drift potential than conventional low/high volume application.

Deposition of aerosol or fine droplets is dominated by turbulence. The shape of the downwind deposit is characterised by a peak approximately five to ten times the release height downwind, with a tail which may extend significant distances downwind under some circumstances.

2.6.15. Large droplet placement (LDP) spraying

Defined as large droplets (>250 µm VMD) applied at rates greater than 30 L/ha.

The use of large droplet placement application may offer advantages when spraying has to be undertaken close to downwind susceptible areas. Large sized droplets (eg. >250 µm) have high sedimentation velocities and are not so greatly influenced by vertical air movement and turbulence as small droplets. If large droplets are produced by an aircraft with the aim of laying down a uniform deposit over the surface of a crop, this is termed large droplet placement or LDP spraying. Generally, such application is undertaken using emulsifiable concentrates (ECs) or wettable powders (WPs) using total water application rates of 30 L/ha+. An aircraft has to fly accurately across a paddock to ensure an even and smooth deposit is 'painted' onto the crop.

LDP application is characterised by:

- Using bulk application rates of 30 L/ha or greater
- Applying sprays when aircraft are positioned straight and level above the crop. Wheel height should not usually exceed 3m above the crop during spraying.
- Using boom lengths of about 65% of the wingspan or less
- Locating the spray boom 25–30 cm below the trailing edge of the wing
- Orientating nozzles parallel with the air stream, ie. parallel to undersurface of wing
- Using liquid supply pressures between 30 and 60 psi or 200 and 400 kPa (nozzle performance dependent)
- Using nozzles that generate droplets greater than 250 µm VMD

Other factors which should be considered include:

- Micronair™ AU5000 nozzles are designed for aerial ULV application (they are not normally used for aerial LDP application). During a ULV application using Miconair AU5000 nozzles, it may be possible to reduce the proportion of the spray comprising droplets less than 100 µm in size by limiting the rotational speed of the cage.
- Wind direction, wind speed, temperature, humidity and stability should be observed and recorded. Smoke or dust can be used to estimate whether unstable, neutral, stable or inversion conditions exist. Spraying should ideally take place in a neutral to slightly unstable atmosphere (Figure 10). Spraying should not take place during highly unstable conditions or when surface temperature inversion conditions exist. Strongly stable conditions should also be avoided.
- Sprays should be applied when the wind direction is away from susceptible areas.
- Wind speed should be between about 4 and 15 km/h for most spraying operations. Spraying should not be undertaken if the wind is light and variable in strength or direction.
- Spraying should ideally be undertaken when temperatures are most favourable (in a 24-hour cycle).

- Spraying of water-based sprays should not take place under conditions of high temperature and low humidity, eg. when the wet bulb depression is greater than about 10°C.

2.6.16. Helicopters

Like fixed-wing aircraft, nozzle type, positioning and orientation on a helicopter are important factors that influence spray drift. However, with helicopters, ground speeds over the crop can be varied significantly and are normally considerably less than equivalent fixed-wing aircraft. Consequently, the effect of blast atomisation can often be reduced and larger droplet sizes generated using helicopters. Additionally, it is possible for helicopters to fly closer to the ground due to the lower flying speed and greater visibility afforded by helicopter design. The factors of lower airspeed and lower operating heights can contribute to lowering the drift potential from rotary wing aircraft (helicopters) as compared with fixed-wing aircraft.

When a helicopter is moving at speed across a crop (say, greater than about 40 km/h), the wake from the helicopter is considered to be similar to that generated by a comparable fixed-wing aircraft. Rotor-tip vortices are generated in a similar way to their production on fixed-wing aircraft. When helicopters are flown very slowly, the airflow about the helicopter is changed markedly and, although wider swath widths can be achieved (caused by air outflow at ground level), droplets can be carried up by rotor vortices and this results in a higher drift potential.

2.6.17. Computer spray drift predictions

Gaussian diffusion algorithms (Cramer *et al* 1972, Bache and Sayer 1975, Dumbauld *et al* 1976) provide an estimation of the downwind distribution of droplets dispersing and settling from a line source. Algorithms of this type are the basis for far wake prediction in other models, eg. FSCBG and AgDRIFT™ (Teske *et al* 1993, 1997), which utilise Lagrangian equations to compute a complex source.

In the early 1970s, the United States Department of Agriculture (USDA) Forest Service supported development work to adapt a simplified aerial line source model for forestry application that had originally been developed for the US army. The modelling efforts resulted in the production of AgDISP (AGricultural DISPersal) and FSCBG (Forest Service Cramer-Barry-Grim) models in the early 1980s. Both were updated and improved in subsequent years and currently AgDISP includes subroutines for aircraft wake effects (such as wing-tip and rotor-tip vortices), vortex decay and droplet evaporation. Based on a Lagrangian approach to the solution of the released particle equations of motion, simple models are used to calculate the effect of aircraft and ambient turbulence. The motion of a group of similar-sized droplets released into the atmosphere from all release points on the aircraft is tracked (Bilanin *et al* 1989).

Optimised for describing aerial application in forests, FSCBG incorporates the near wake effects of AgDISP and predicts downwind dispersion. Once the near wake effects have sufficiently decayed, a Gaussian diffusion model (far wake) is used to predict dispersal. FSCBG version 4.3 has an additional feature over previous versions that can alter the change-over between the near wake and far wake models. It is possible to use either the near wake model or the far wake (Gaussian) model on its own.

From 1992–1995, the Spray Drift Task Force (SDTF), a consortium of 40 chemical manufacturing companies, in response to a directive from the US Environmental Protection Agency (EPA), conducted a series of field and laboratory studies to develop a database and spray drift model to assist in the registration of farm chemicals. Committing some US$20 million to the project, a model was developed to assist regulatory authorities assess off-target risks based on realistic input parameters instead of prescriptive threshold values. The model, termed AgDRIFT™ was developed from both FSCBG and AgDISP.

The results of a sensitivity analysis using AgDRIFT™ to assess the effect of wind speed, temperature relative humidity, boom length, aircraft speed, droplet size (using BCPC curves) and flying height are presented in Figure 21. For the sake of completeness, the top right diagram includes a similar analysis for turbulence intensity using a Gaussian diffusion model (Craig *et al* 1998a). Constants used for the analysis are shown in Table 6.

The *y*-axis for each graph shows the percentage (0–5%) of the applied rate that is deposited 500 m downwind of the sprayed area. Trends that increase droplet transport downwind are clearly indicated, namely:

- a reduction in droplet size
- increasing release height
- increasing boom length
- increasing aircraft airspeed
- increasing wind speed
- increasing temperature and low relative humidity
- (low turbulence intensity)

Droplet size	**Medium VMD = 216 μm D[v 0.1] = 95 μm D[v 0.9] = 369 μm**
Material	water
Wind speed	3 m/s
Direction	–90 deg
Temperature	30°C
Relative humidity	50%
Aircraft	AT 502
Aircraft speed	60 m/s (115 knots)
Boom height	3m
No. of flight lines	20
Swath width	25
Surface roughness	.0075

Table 6. Constants used in AgDRIFT™ sensitivity analysis.

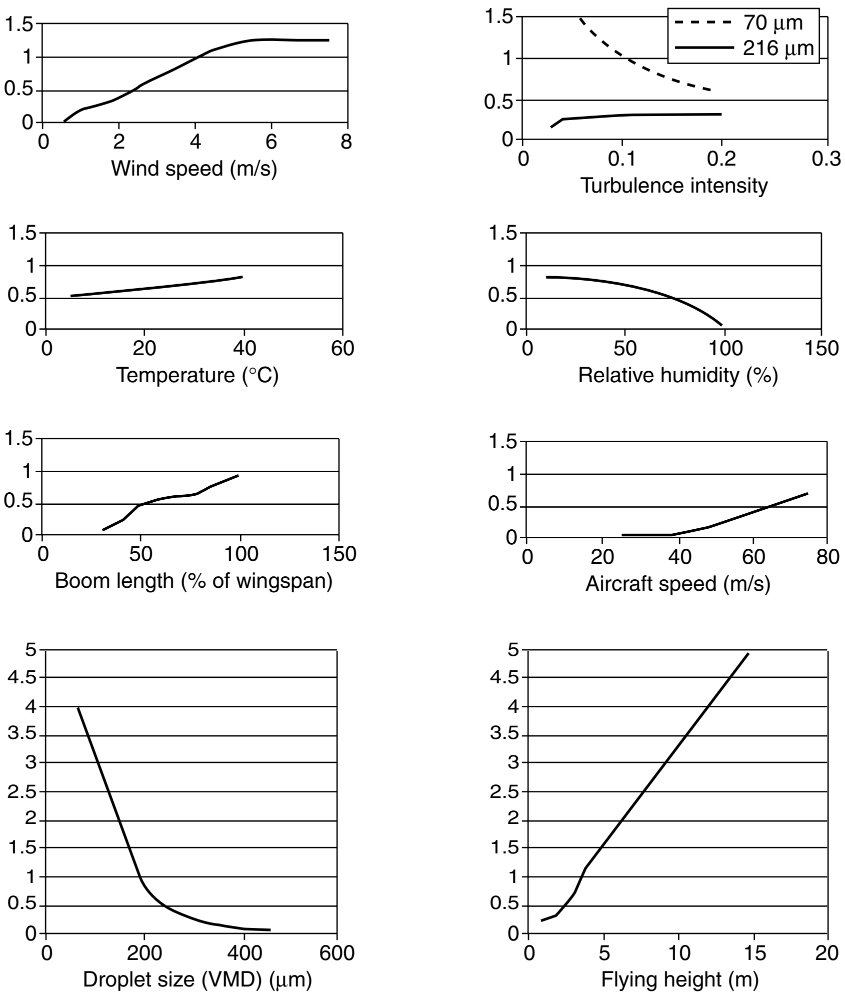


Figure 21. Summary of various application parameters on aircraft spray drift deposition at 500 m downwind of field (expressed as % applied rate).

2.6.18. Summary of drift mitigation studies – key points

Large droplets and in-crop downwind offset buffer zones can reduce both airborne and deposit drift values. However, such strategies should always be used in conjunction with other valuable techniques. The use of single strategies may not be sufficient on their own to have a significant effect on pesticide drift management. To supplement the adoption of LDP techniques (in the case of aerial application), and the use of in-crop offset buffer distances, some important supporting drift mitigation procedures are summarised below:

- Identify all areas around an area to be sprayed that could be susceptible to spray drift damage.
- Communicate on a regular basis with neighbours regarding proposed spray schedules and activities.

- Maintain copies of relevant material safety data sheets (MSDS).
- Read, understand and heed the pesticide product label prior to spraying.
- Observe and record wind direction, wind speed, temperature and humidity prior to and during application.
- Avoid spraying when wind is blowing towards susceptible areas.
- Spraying should not be undertaken if the wind is light and variable in strength or direction.
- Spraying of water-based sprays should be undertaken when temperatures are most favourable (in a 24-hour cycle).
- Spraying of water-based sprays should not take place under conditions of high temperature and low humidity.
- Spraying should ideally take place when atmospheric conditions are neutral.
- Spraying should not take place during highly unstable conditions.
- Spraying should not take place during highly stable conditions or when surface temperature inversion exists.
- Where appropriate, spraying should be undertaken on the upwind section of a field, such that the unsprayed downwind section is used to retain spray drift (field splitting).
- Spraying should, where possible, be carried out with a crosswind, and progress upwind.
- Sprays should be applied when aircraft are straight and level above a crop.
- Smoking devices should be used to monitor changes in wind direction and stability.
- Ensure that equipment is correctly calibrated, and with aircraft, that optimum flight lane separations are used.

2.7. Training

Training of chemical users can improve the efficiency of their spray applications and reduce the likelihood of off-target spray drift. Agricultural chemical users should be qualified according to relevant State/Territory training and accreditation requirements.

All chemical users should be encouraged to undertake farm chemical user training as a minimum requirement for the use of agricultural chemicals.

Where required, aerial operators, pilots, and commercial ground chemical users must be licensed according to State/Territory and Commonwealth regulatory requirements and be appropriately trained. This may include, for example (for pilots), holding accreditation under the Aerial Agricultural Association of Australia's Operation Spraysafe Program.

2.8. Record-keeping

Maintaining records of chemical use is now mandatory for chemical users in many States. Good records help document the pattern of chemical use on a property and contribute to the management of efficient enterprises.

Records should be kept covering the following:

1 staff development/training

2 equipment maintenance/calibration

3 spray application operations including property plans, operational plans (detailing awareness zones), individual spray job details and weather observations

4 chemicals in storage and MSDS

5 communications with neighbours regarding spray drift issues.

3

Operational planning

The principles of spray drift management set out in Section 1 of this document present a series of issues that should be considered by the chemical user before any application is undertaken. These issues have been reinforced and supported by a series of strategies. To assist in understanding the relationship between the various issues discussed in Section 1, an overview of the process is presented in the flow diagram below (Figure 22).

3.1. Developing an operational plan

This flow diagram (Figure 22) can be used to develop an operational plan. An operational plan is the document used to plan and undertake a specific spray application task. A plan should be developed as part of every spray application task.

The operational plan should be kept with all other documentation listed in Section 1.8. The plan should consist of three decision-making phases: i) Planning – pre-spray, ii) Application, and iii) Post-spray evaluation. Phase (i) involves deciding whether spraying is absolutely necessary or can be avoided by the use of alternative pest control methods (such as listed in Section 1.4.). Once the weather has been accurately assessed and an up-to-date awareness zone map consulted (eg. Figure 23), a decision to apply the spray can be made. All phase (ii) parameters should be carefully considered and information recorded with every step.

Finally, once spraying is complete or is terminated, phase (iii) can be conducted. This involves making summary statements regarding the outcome of the spray application task. A sample operational plan in the form of a checklist is shown in Table 7.

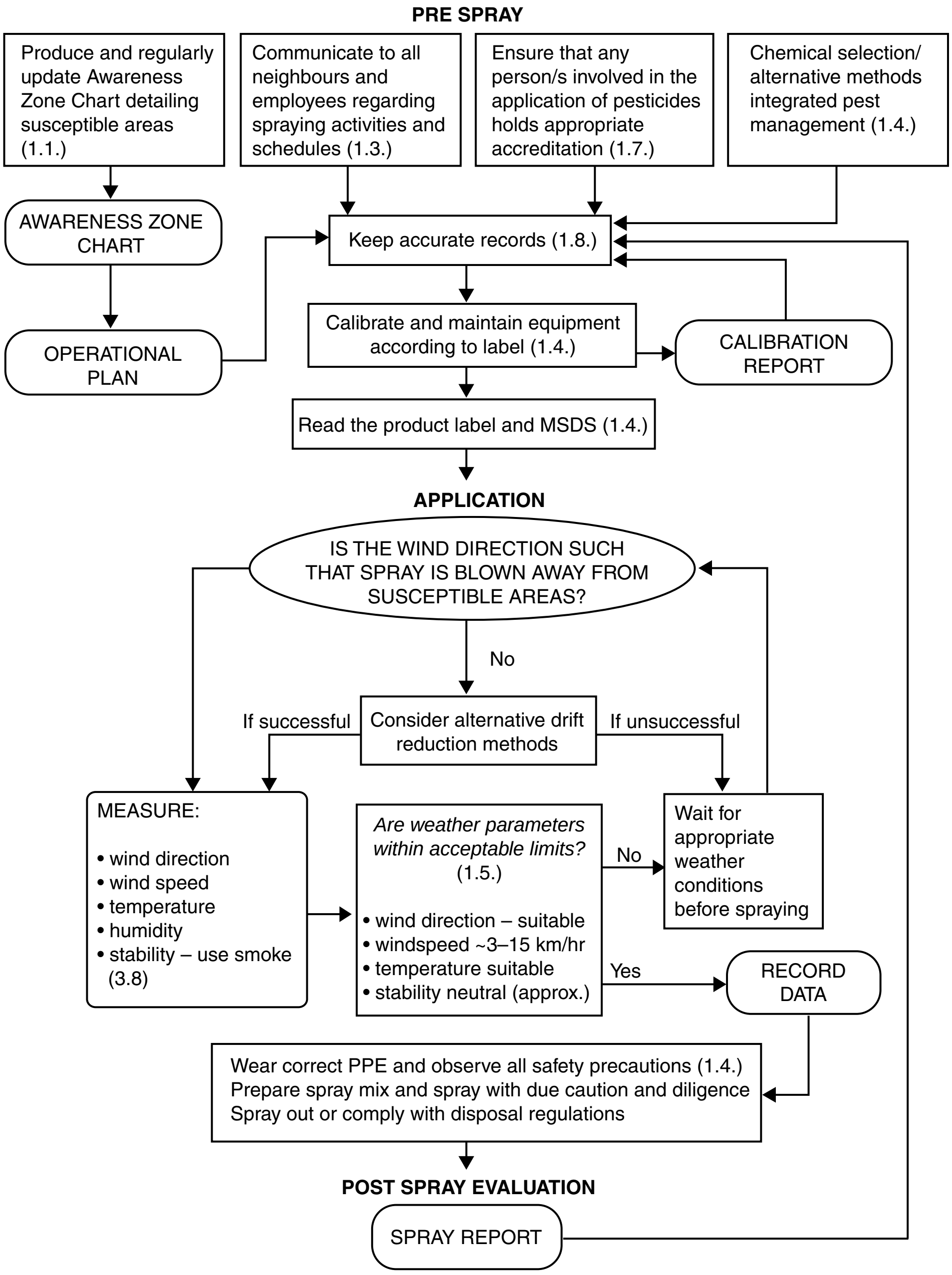


Figure 22. An overview of the national guidelines basic framework.

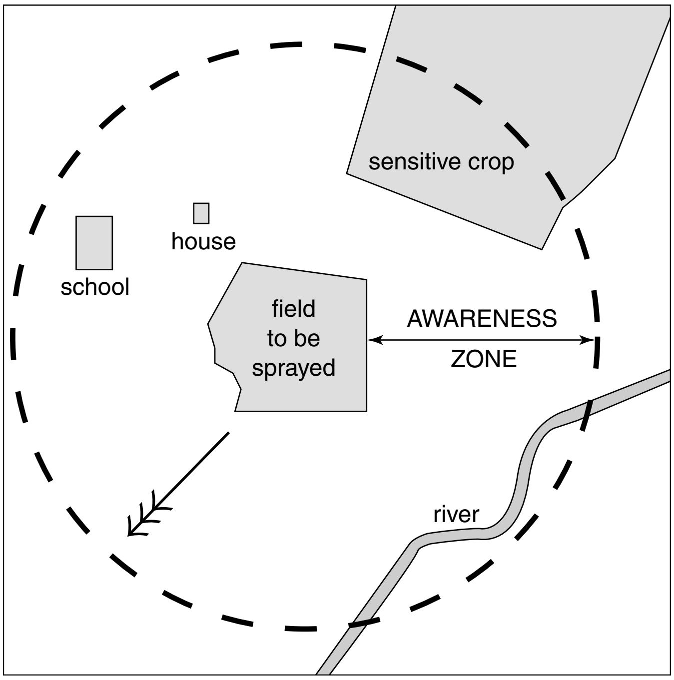


Figure 23. Example of a typical awareness zone to be utilised during operational planning.

Overview checklist

Task	Tick	Notes
PLANNING – PRE-SPRAY		
Chemical user		*Joe Bloggs*
Field owner		*Fred Bloggs*
Location	✓	*6 km SE of Countrytown*
Field to be sprayed, area (hectares) and type	✓	*14 ha fallow*
Nature of pest problem	✓	*Ryegrass*
Are there any alternative methods to spraying?	✓	*No*
Consult an up to date awareness zone chart	✓	*Yes*
Sensitive areas within awareness zone	✓	*Cotton 1 km to NE*
Communicate to neighbours	✓	*Yes, by phone 5/7/99*
Check user training credentials	✓	*ChemCert 15/12/98*

Task	Tick	Notes
APPLICATION		
Equipment in proper working order and calibrated	✓	*Leak repaired*
Spray equipment	✓	*SprayCoup*
Nozzle type		*Flat fan 8002*
Nozzle number		*50*
Droplet size		*BCPC medium*
Settings	✓	*Vertical*
Spray pressure (bar)	✓	*2 bar*
Product label and MSDS read and understood	✓	*Yes*
Check wind direction – away from susceptible areas	✓	*Yes*
Wind direction (°)	✓	*From NE 040°*
Wind speed (kph)	✓	*10 kph*
Temperature (°C)	✓	*27°C*
Relative humidity (%)	✓	*50%*
Cloud cover (1/8ths)		*2/8*
Approximate stability class (unstable, neutral or stable)		*Neutral*
Is there a ground surface temperature inversion?		*No*
Are weather parameters within acceptable limits?	✓	*Yes*
Are you wearing correct PPE for the job?	✓	*Yes*
Date		*13/12/98*
Time start of spraying		*10.00 hrs*
Time end of spraying		*16.00 hrs*
Chemical name(s)	✓	*Glyphosate 450*
Product application rate (L/ha or kg/ha)		*2.5 L/ha*
Bulk volume rate (L/ha or kg/ha)	✓	*50 L/ha*
Amount of product used		*35 L*
Treated area (ha)		*14 ha*
In-crop/other buffer used?	✓	*100 m in-crop strip*
POST-SPRAY EVALUATION		
Were results satisfactory?	✓	*Yes*
Could there be any improvements?	✓	*No*
All spray records correct, up-to-date and stored safely?	✓	*Yes*
Full name of chemical user _______________ Signature _____________ Date __________		

Table 7. Sample operational plan.

4

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Acronyms and abbreviations

ai (or ac)	Active ingredient (or constituent) of an agricultural chemical.
ASAE	American Society of Agricultural Engineers
Awareness zone	An awareness zone is an arbitrary zone placed around an area to be sprayed. It is used to assist chemical users identify non target areas around a crop or field to be sprayed that might be susceptible to spray drift, and to develop strategies to minimise risk.
BCPC	British Crop Protection Council
Buffer zone	A buffer zone is an area of land located on the downwind side of a sprayed area, used to protect an area susceptible to spray drift.
EC	Emulsifiable concentrate
LDP	Large droplet placement. A LDP spray is a water-based spray, usually applied by air that has a coarse droplet size distribution, ie. VMD values greater than about 250 µm.
LV	Low volume. A LV spray is usually applied (by air) at 10–50 L/ha.
Micrometres (µm)	A micrometre (or micron) is defined as one millionth of a metre (m) or one thousandth of a millimetre (mm).
MSDS	Material Safety Data Sheet. Information provided by manufacturers that presents technical and safety information on the use and handling of chemicals.
NEC	No Effect Concentration
PEC	Predicted Environmental Concentration
PPE	Personal protective equipment
SC	Suspension concentrate

ULV	Ultra low volume. A ULV spray is an oil-based pesticide spray that is applied without an additional carrier at very low volume application rates (usually <5 L/ha). Usually these formulations are applied using small droplet sizes, ie. VMD values less than 100 µm.
Vegetative barrier	A vegetative barrier is usually a crop, tree or shrub line that is located on the downwind side of a sprayed area to protect an area susceptible to spray drift. Vegetation is sometimes planted deliberately to filter spray drift from the environment.
VMD	Volume Median Diameter (µm). The VMD is the droplet size that divides a droplet spectrum in half by volume. Half the volume of the spray is contained in droplets greater than the VMD and half the volume is contained in droplets smaller than the VMD.
WP	Wettable powder