Food and Agriculture Organization of the United Nations

World Health Organization

International Code of Conduct on Pesticide Management

Guidance for aerial application of pesticides

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Preface

Since 1995, the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) have worked to improve the safety and efficiency of pesticides and application equipment and to reduce the associated risks in the framework of sustainable agriculture, integrated pest management, public health and integrated vector management (IVM). The work began in 1997 with the publication of FAO guidelines for controlling the quality of pesticide application equipment. In 2001, FAO issued the *Guidelines on Good Practice for Aerial Application of Pesticides.*[1] This present version, developed by FAO and WHO, covers new developments in aerial application of pesticides since 2001.

This publication was drafted by Dr Jane Bonds (FAO consultant) according to the latest guidance for implementing *The International Code of Conduct on Pesticide Management* (referred to hereafter as the *Code of Conduct*) and its technical guidance series,[2] and with the FAO/WHO Joint Meeting on PesticideManagement (JMPM). It was then reviewed by JMPM expert members, representatives of the Observer organizations, and FAO and WHO staff. Dr Bonds made subsequent revisions on the basis of the comments and technical contributions received from reviewers.

This guidance reflects international developments in pesticide and chemical management, including adoption of strategic frameworks such as the *Strategic Approach to International Chemicals Management.*[3] It also reflects improvements in adoption of integrated pest and vector management, and sharing of information and training to encourage selection of the least hazardous pesticides, such as safer chemicals, biopesticides and natural control agents. More attention has been paid to human health and environmental protection, resulting in revised regulations and measures to restrict and regulate risks specific to aerial pesticide applications.

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The following FAO and WHO JMPM Secretariat staff made technical contributions and finalized the content for publication: Mr Baogen Gu and Mr Milan Ivic (Plant Production and Protection Division, FAO, Rome, Italy); Mr Richard Brown (Department of Environment, Climate Change and Health, WHO, Geneva, Switzerland); and Mr Rajpal S. Yadav (Department of Control of Neglected Tropical Diseases, WHO, Geneva, Switzerland).

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Declarations of interest

FAO and WHO reported that they had received and reviewed declarations of interest from all FAO and WHO expert panel members who participated in the 14th and the 15th JMPM and had concluded that none could give rise to a potential or reasonably perceived conflict of interest related to the subjects discussed at the meeting.

Abbreviations

AGDISP™	AGricultural DISPersal
AIMMS	Aircraft integrated meteorological measurement system
ANAC	National Agency of Civilian Aviation
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographical information system
GPS	Global positioning system
IVM	Integrated vector management
JMPM	Joint Meeting on Pesticide Management
LV	Low volume (5–50 L/ha)
MAPA	Ministry of Agriculture, Livestock and Food Supply
PPE	Personal protective equipment
QR	Quick response (digital code)
RPM	Revolutions per minute
UAS	Un-crewed aerial system
UASS	Un-crewed aerial spraying system
ULV	Ultra-low volume (< 5 L/ha)
URL	Universal resource locator
USEPA	United States Environmental Protection Agency
WHO	World Health Organization

Glossary

Adjuvant. Material added to a pesticide mixture to improve or alter its deposition, toxic effects, miscibility, persistence or another quality of the active ingredient.

Aerial application. Application of a product from an aircraft.

Boom. A structure attached to an aircraft to which spray nozzles are attached.

Buffer zone. An area that is not treated with a pesticide in order to protect adjoining areas from pesticide hazards; the distance between the point of direct pesticide application and the nearest downwind boundary of a sensitive area; also referred to as a "setback" or a "no-spray" area.

Carrier. The liquid or powdered inert substance that is combined with the active ingredient in a pesticide formulation; applies to water, oil or another substance.

Drift. Movement of pesticide through the air at the time of application or soon thereafter, from the target site to any non- or off-target site; excludes pesticide movement by erosion, migration, volatility or on wind-blown soil particles after application.

Driftable fine. Spray droplets ≤ 150 µm.

Droplet spectra. Classification of spray droplets into eight categories according to their volume median diameter: extremely fine, very fine, fine, medium, coarse, very coarse, extremely coarse, and ultra coarse.

$DV_{0.5}$ or volume median diameter. The median droplet diameter when half of the volume of spray consists of droplets with a smaller diameter and the other half of droplets with a larger diameter.

$DV_{0.1}$. Droplet diameter when 10 percent of the volume of spray consists of droplets with a smaller diameter,which may contain most of the fine driftable droplets.

$DV_{0.9}$. Droplet diameter when 90 percent of the volume of spray is in droplets smaller (or 10 percent larger) than this value.

Flight line. Centreline of the flightpath taken by the aircraft during the application.

Geographical information system (GIS). A computer system for capturing, storing, checking and displaying data on positions on the earth's surface.

Global positioning system (GPS). A navigational device for determining the receiver's position from signals from satellites.

Integrated pest management. Careful consideration of all available pest control techniques and integration of appropriate measures to discourage the development of pest populations and keep the use of pesticides and other interventions to economically justified levels and to reduce or minimize risks to human and animal health and/or the environment; promotes the growth of healthy crops with the least possible disruption to agroecosystems and natural pest control mechanisms.

Integrated vector management. Rational decision-making for optimal use of resources for disease vector control to improve the efficacy, cost-effectiveness, ecological soundness and sustainability of disease vector control interventions for control of vector-borne diseases.

Label. The written, printed or graphic matter on or attached to a pesticide or its immediate container and also to the outside container or wrapper of the retail package of the pesticide.

Light bar. An array of lights on an aircraft-mounted global positioning system that enables the pilot to locate the centre of each spray swath.

Low volume. Application of liquid pesticides at a rate of 5–50 L/ha.

Payload. The weight of passengers and equipment in an aircraft.

Personal protective equipment (PPE). Clothes, materials or devices that provide protection from exposure to a pesticide during handling and application; specifically designed protective equipment and clothing reserved for pesticide application and handling.

Prescription map. Map that contains information on the quantity of a product (fertilizer, seed, pesticide) to be spread or applied on each area of a field.

Safety data sheet. A document available from the manufacturer that provides information on chemical properties, toxicity, first aid, hazards, personal protective equipment, and emergency procedures to be followed in the event of a spill, leak, fire or transportation accident.

Swath (or swath width). The area covered by one pass of pesticide application equipment.

Temperature inversion. Increase in temperature with height, in which vapours of the pesticides applied can become trapped and concentrated and are moved away from the treatment area, potentially causing damage or injury at another location.

Ultra-low volume (ULV). Application of liquid pesticides at a rate of < 5 L/ha.

Un-crewed aerial system (UAS). Any aircraft operating or designed to operate automatically or to be piloted remotely.

Un-crewed aerial spray system (UASS). An aircraft specifically designed to apply a pesticide product automatically and to be piloted remotely.

Wing-tip vortex. The circular or spiral swirling of air caused by the wing tips of an aircraft, resulting in entrapment of spray droplets, which affects their dispersal.

1. Introduction

1.1 Background

Most technological developments made have been to improve the precision of pesticide application by use of global positioning systems (GPS) and geographical information systems (GIS), which improve the accuracy of pesticide application. Other new techniques include mapping, prediction models, real-time sensors, variable rate systems and developments in atomizer technology. One of the most notable developments is the use of "un-crewed aerial systems", often referred to as "drones". In this guidance, drones used for applying pesticides are referred to as "un-crewed aerial spraying systems" (UASS) to distinguish them from un-crewed aerial systems, which are the platforms used for imagery, without a spray system.

The advantages and disadvantages associated with the use of aerial application methods are listed in Box 1. It is important to compare the risks with those of other application methods and also alternative approaches to controlling pests and diseases.

Box 1. Advantages and disadvantages of aerial application

Advantages	Disadvantages
Larger areas treated in a shorter time than with ground applications and access to areas that cannot be reached with ground equipment.	Crewed aircraft are more expensive and technically more complex than many ground application devices; however, UASS provide a cheaper aerial platform that is easier to operate.
Timely applications result in more effective pest control.	Off-target losses may be higher than with conventional application techniques.
Operators are less exposed, especially as compared with knapsack sprayers, who walk through a sprayed crop.	Increased risk of physical harm and danger of collisions.
Potentially lower cost per unit area for large land areas with crewed aircraft and more effective working rates.	Trees, waterways, overhead power lines, and other environmental considerations may prevent spraying of some fields with crewed aircraft.
Agriculture: smaller volume of water than with most ground applications.	Crewed aircraft operate at high forward speeds, which require higher flow rates, which can increase the risk of incompatibility in tank mixtures.
Agriculture: Can reduce soil compaction, which can damage crops, and fields can be treated when the ground is too wet or inaccessible for ground equipment.	Accurate targeting of small areas or high-resolution prescription mapping may be more difficult with crewed aircraft.
Can reach crop canopies that are too dense or tall to be reached with ground equipment.	The release height increases sensitivity to adverse meteorological conditions.
Reduced spread of pests, while ground equipment can carry pests from one field to the next.	Crewed fixed wing: require a safe landing strip within a ferrying distance of the target zone.

FAO and WHO promote integrated pest and vector management, which combines biological, chemical, physical and crop-specific (cultural) management strategies and practices for managing pests and minimizing the use of pesticides, thus reducing or minimizing the risks posed by pesticides to human health and the environment as well as problems of pest resistance, for sustainable pest management.

The choice of platform for aerial application depends on various physical and mechanical factors but predominantly on the area to be treated. The UASS with a smaller payload tend to be used to treat smaller areas, while the size and speed of crewed fixed-wing aircraft restricts them to large-acreage areas. Crewed helicopters can spray larger areas, and because of their manoeuvrability, can also be used to treat smaller areas. Use of aircraft allows operators to avoid certain obstacles, such as difficult terrain. Other obstacles, such as houses, trees, waterways, and overhead power lines, may limit treatment options.

Most aircraft used today in aerial pesticide application are equipped with GPS, and in many applications, use of GPS is mandatory. FAO requires that all spray aircraft used in locust control have accurate GPS guidance.

In public health vector control applications and migrant pest (locust) control, aircraft are used for rapid response and wide area coverage. Ultra-low volume (ULV) application of pesticides to control adult mosquitoes (typically, < 100 ml/ha) can be done from both crewed and un-crewed aircraft, making wide area applications logistically feasible. For locust control, the volumes applied are still lower (< 1 L/ha) than for other agricultural uses, but wide-area application is logistically less feasible with UASS. New technology with swarms of UASS may allow un-crewed vehicles to spray wider areas, although swarm operations may be costly and logistically difficult. The UASS with a larger payload and greater endurance are also being discussed; however, the larger they become, the more technically complex is the operation, which might detract from their advantage of relatively non-specialized equipment as compared with crewed aircraft.[4]

In agriculture, precisely delimited fields are the target. This presents the greatest risk for off-target losses, possibly exposing non-target crops, habitats, species and residential communities. Many of the technical advances in aerial application over the past twenty years are concerned with minimization of off-target and non-target exposure. The technical developments include low-drift nozzle technology and areduction in driftable fine droplets, use of a mechanistic spray dispersion model to adjust infield buffersor offsets in response to real-time meteorological information, and prescription maps and variable ratetechnology to minimize the quantity of product applied.

From a mechanical perspective, aerial applications are often perceived as dangerous because of their size, speed and low-altitude navigation. They are, however, one of the most technically advanced and well-supported application methods. Under certain conditions, aerial applications may be considered safer than ground application and the only logistically feasible option, such as for pesticide application on steep slopes or over large remote areas. In terms of operator exposure, they can be considered safer than most ground equipment because of the separation of the pilot in a sealed cockpit on crewed aircraft, outside the application area for UASS operators. In regions where rural communities live in and around target areas, care must be taken to designate appropriate no-spray or buffer zones.

Both aerial and ground application methods are of potential concern, although the scenarios for authorized use are well established and supported by advanced risk assessment methods. There is potentially more spray drift from aerial applications than from most ground application equipment. As with all spraying techniques, environmental contamination can be significant, particularly if operations are not correctly executed. Models have been developed to ensure correct application. Empirical models are used to predict off-target movement of pesticides, and a mechanistic model, AGricultural DISPersal (AGDISP™),[5] has been developed specifically to predict off-target movement for aerial applications. This model is used in Australia by the Australian Pesticides and Veterinary Medicines Authority, in Canada by the Pest Management Regulatory Agency, and in the United States by the Environmental Protection Agency (USEPA),[5] to make regulatory decisions on spray drift from crewed aerial applications and subsequent demarcation of no-spray buffer zones for certain compounds. In a rough ranking, potential drift in agricultural practices would pose the highest to the lowest risk as follows: crewed aerial application, orchard air blast, UASS, tractor boom, and backpack spraying.

It remains to be seen whether models of potential exposure will be applicable to un-crewed systems, because of their small size, slow speed and differences in style. For example, the AGDISP™ model is applicable only for single-rotor helicopters and fixed-wing aircraft and is not validated for multiple rotors, as in many UASS. The model might be applicable for large single-propeller and fixed-wing UASS, but empirical data would be required for validation. A proprietary model AGDISPpro is designed to simulate UASS, but its library is currently limited. Considerable work is under way internationally to better describe off-target movement with UASS. In general, guidance for UASS should be developed that includes UASS-specific pesticide label language.

Recent research and developments in aerial application have focused on precision pesticide application. Because of the rapid uptake of global navigation satellite systems (GPS and real-time kinematics GPS) and GIS, nearly all aircraft have on-board navigational technology. Such equipment not only guides the pilot to the flight line but also integrates prescription maps, which allow the applicator to select target zones for treatment, as opposed to whole-field broadcast applications. These guidance systems have improved safety by removing the requirement for flagmen and ensuring that ground crews are at a safe distance from the application. Other sensors, such as on-board meteorological measurement systems integrated with spray drift models, enable applicators to respond to changes in wind speed and direction and to adjust flight lines to maximize on-target and minimize off-target movement of spray. Research is under way to combine on-board meteorological measurement systems, GPS, modelling, and individual nozzle control by pulse-width modulation, to create a spray system that automatically adjusts output for factors such as crosswind, prescribed application zones, and required changes in droplet size to minimize drift adjacent to sensitive areas.

1.2 Objectives

The objective of this guidance is to inform the reader about appropriate regulations and management practices for aerial application of pesticides. It provides:

- updated guidance on regulatory and technical requirements for authorities, licensed operators andapplicators;
- information for regulators in making informed national or regional decisions about registration andlicensing of aerial applications according to different use patterns and newer vehicle types, such asUASS; and
- information on measures to minimize off-site movement and risks associated with aerial application of pesticides.

This guidance is complementary to national codes of practice for pesticide use and application and national civil aviation regulations. It is essential to refer to existing legislation, as failure to comply may have legal implications.

1.3 Target readership

The publication offers guidance to regulatory authorities, licensed operators and applicators involved in aerial application of pesticides. The main readers will be regulators in low- andmiddle-income countries, which may not have systems for appropriate certification and regulation of aerial pesticide application for agricultural pest control or public health vector control.

Other potentially interested readers are those involved in aerial spray operations, including applicators (growers, spray contractors, pilots, loaders, observers); governments (ministries and agencies of, e.g. agriculture, health, transport, environment, civil aviation, industry, security); other regulators involvedin public amenities; and national, regional and local inspectors of aerial spray operations.

1.4 Scope

This publication provides guidance on regulations and best management practices for aerial application of pesticides in agriculture, forestry, public health, and migrant pest control. Aerial platforms are usedin many ways, and products may be applied as liquids, dusts or granules. Effective, safe aircraft application requires:

- well-organized spray operations;
- fully trained people who are aware of their roles and responsibilities;
- avoidance of exposure of bystanders to spray drift; and
- prevention of contamination of the environment, including water bodies, ecosystems andfoodstuffs.

The guidance covers use of crewed and un-crewed fixed-wing and rotary aircraft for:

Crop protection and forestry. The target is cultivated areas, and the aim of aerial application is precise delivery of the desired amount to that target area, avoidance of off-target movement, appropriate timing, and better access and logistics.

Large-scale locust and migrant pest operations. The target is the infestation itself and the vegetation it will consume. The timing of application is critical as the swarm may differ in size, shape, and geographical location. During the adult swarming phase of locusts, their flight height requires aircraft to operate at increased heights which could cause increased spray drift. During the flying swarm stage, locusts cover an area that is 10–20 times larger than that for roosting, which increases application costs and risks to the environment as pesticide is applied over larger areas.

Public health. To control adult mosquitoes (adulticiding), spray is applied in an ultra-fine droplet size distribution during crepuscular hours and darkness and is intended to drift through the target zone. The aim is to kill flying mosquitoes, often in residential or urban areas where the vector species is transmitting diseases to humans. In aerial adulticiding operations, pesticide deposition on the ground is considered a loss and is mitigated by maintaining a suitably small droplet size for the relative density of the compound. Larviciding and snail control are used to control juvenile stages of mosquitoes and snail hosts, with a deposition spray or granular application on surface waters or wetlands.

2. Elements for deciding to register a pesticide for aerial application

This section provides elements for governments to consider before registering a pesticide for aerial application. The decision to use a pesticide for aerial spraying should be taken only after alternative measures have been considered as part of an integrated pest and vector management programme.

2.1 International trends

Aerial pesticide application is common in many countries. Crewed aircraft are used mainly in countries with large-acreage farms. The United States is the world's largest user of crewed aerial pesticide application. In 2020, the industry annually treated:

- 51 million ha of cropland;
- 1.9 million ha for mosquito control;
- 2.06 million ha of forest;
- 3.2 million ha of pasture and range land;
- 0.08 million ha of rights of way; and
- 0.28 million ha for aquatic weed control.

The approximate numbers of crewed agricultural aircraft used are 3 600 in the United States, 2 280 in Brazil, 2 000 in Mexico, 1 200 in Argentina and 300 each in Australia and New Zealand. In the European Union, the *Directive 2009/128/EC on the sustainable use of pesticides* prohibits aerial applications to protect human health and the environment.[6] All twenty-seven European Member States have prohibited aerial spraying, but twenty-one allowpossible case-by-case derogations, and in 2015, at least nine Member States granted derogations covering just over 450 000 ha. Most (90 percent) applications in Europe during 2019 were in Spain (362 660 ha) and Hungary (about 88 000 ha).[7] A trend to use UASS for pesticide application has been seen in some parts of the world, particularlyfor small acreages and high-value crops. Use of UASS has been reported for application of pesticides on a wide range of crops in China, Japan and the Republic of Korea. China is the world's largest user of UASS: in 2020, approximately 110 000 UASS were used to treat more than 66.7 million ha.

2.2 The International Code of Conduct on Pesticide Management

The International Code of Conduct on Pesticide Management outlines the responsibility of governments and industry to minimize risks associated with pesticides throughout their life cycle. Several articles of the code should be considered when selecting an application method (Box 2).

Box 2. Goals of The International Code of Conduct on Pesticide Management

Article 3.11: Governments, pesticide industry and the application equipment industry should develop and promote theuse of pesticide application methods and equipment that minimize the risks from pesticides to human and animal health and/or the environment and that optimize efficiency and cost–effectiveness, and should conduct periodic practical training in such activities. The application equipment industry should also provide users with information on proper maintenance and use of application equipment.

Article 4.5: Pesticide industry and governments should collaborate in post-registration surveillance and conductingmonitoring studies to determine the fate of pesticides and their health and environmental effects under operational conditions.

Article 5.1.10: Governments should utilize all possible means for collecting reliable data, maintaining statistics onenvironmental contamination and adverse effects, and reporting specific incidents related to pesticides.

Article 5.2.4: Pesticide industry should make every reasonable effort to reduce risks posed by pesticides by developingapplication methods and equipment that minimize exposure to pesticides.

Article 7.2: When determining the risk and degree of restriction appropriate to the product, the responsible authorityshould take into account the type of formulation, method of application and its uses.

Source: FAO and WHO. 2014. *The International Code of Conduct on Pesticide Management.* Rome, FAO.

2.3 Legal considerations

Aerial application of pesticides is governed by the broad legal obligations applicable to pesticide management stated in international law and in regional, national and even subnational legislation.[8] Thus, this guidance on aerial application should be interpreted and applied in accordance with existing obligations under national and international law, including environmental conventions, human rights treaties, other human rights instruments, and voluntary commitments made under applicable regional and international instruments. In relation to aerial spray, consideration must be given to Indigenous Peoples' free, prior and informed consent,[a] and their collective right to lands, natural resources and territories must be respected. Nothing in the provisions of this guidance publication should be read as limiting or undermining any legal obligations to which a state may be subject under international law. This publication complements and supports national, regional, and international obligations and initiatives to respect, protect and fulfil human rights.

2.4 Registration of products

Authorization and selection of aerial spraying are based on decisions of need, risks, and benefits, which must be addressed before selecting a product and the method of application. Conducting a risk assessment during pesticide registration can mitigate unintended harmful effects.[9] Many countries have legislation to control and regulate the manufacture, importation, distribution, sale and use of pesticides. Products are registered for use after a review of their hazards, risks, and safety, with local field evaluations of efficacy. Only products that are approved for aerial application may be used.

In pesticide registration, responsible authorities authorize the sale and use of pesticide products in their territorial jurisdictions. The decision is based on an evaluation of scientific data that demonstrate that the product is effective for its intended purpose and does not pose an unacceptable risk to humans, wildlife, or the environment. Pesticides are usually specifically authorized for aerial spraying, and many regulatory authorities include such authorization in labelling requirements. The web-based FAO Pesticide Registration Toolkit[10] supports pesticide registrars in developing countries in evaluating and authorizing pesticides. The toolkit includes links to many pesticide-specific sources of information on pesticides, such as registrations in other countries, scientific reviews, hazard classifications, labels, maximum residue levels and pesticide properties.[9]

Particular consideration should be given to aerial application of highly hazardous pesticides. The FAO/WHO *Guidelines on Highly Hazardous Pesticides* [11] provide a process for ensuring that the risks of highly hazardous pesticides are addressed in a need or risk assessment and consideration of appropriate risk mitigation.

[a] The normative framework of free, prior and informed consent includes the *United Nations Declaration on the Rights of Indigenous Peoples*, the International Labour Organization's *Indigenous and Tribal Peoples Convention, 1989 (No.169)* and the *Convention on Biological Diversity*, as well as national laws.

Selection of a pesticide product can be based on the FAO three-step approach to pesticide risk reduction,[9] so as to:

- determine the extent to which pesticide use is necessary and make optimum use of nonchemicalpest management to avoid unjustified pesticide use;
- select the least hazardous pesticide for a particular pest problem and/or a formulation that posesthe least risk; and
- ensure correct use of the selected product.

2.5 Cost

The main reasons for choosing aerial application are cost, speed, and timeliness of application. For application at landscape scale), the approximate cost of crewed aerial application is about USD 25–37/ha. Ground applications can cost from USD 62/ha for broadcast spraying from a truck to ≥ USD 740/ha for backpack application. The estimated cost of mosquito control by larviciding is USD 103/ha for a hand or compression sprayer, USD 34/ha for a motorized backpack, USD 23/ha for a truck-mounted sprayer, USD 34/ha for a helicopter and USD 21/hafor a fixed-wing aircraft. These numbers from Manatee County Mosquito Control District (FL) (2022) show that, when treatment sites are suitably large for aerial application, this method is comparable to or better than ground application. These data reflect basic operating costs, and it could be argued that they do not account for the fact that ground equipment cannot be used in large, flooded areas. Moreover, crewed aircraft cannot effectively target small, disperse habitats. The wide area, high-resolution capacity of UASS makes them a candidate for this type of application.

The UASS-based application technology is considered to be a highly efficient alternative to backpack spraying and less expensive than crewed aerial application. Data are not, however, currently available for comparing the exact costs of UASS with those of other technologies.

3. Mitigation

3.1 Aerial spray drift

Spray drift at the application site is the responsibility of the applicator. The wide area covered by broadcast aerial application can raise concern about spray drifting into non-target areas and potential exposure of bystanders. In some countries, agricultural and forestry aerial applicators are required to notify relevant parties in order to exclude bystanders from a predefined application area. In locust control, the application zones are usually in rural areas, where bystanders and operators can be excluded. In ULV applications for public health, the chemical concentrate (volume mean diameter [$DV_{0.5}$] < 50 µm) is applied in quantities of < 100 ml/ha from an application altitude of > 30 m, and regulatory authorities have determined that potential bystander exposure does not outweigh the health benefits. If there is concern about bystander or non-target exposure, a buffer zone should be defined to protect communities.

In agriculture, the most effective way of reducing drift from aerial spraying is to apply the largest droplets that provide sufficient coverage and control (see Figure 1 and Figure 2). Application of larger droplets and minimizing the number of droplets < 150 µm "driftable fines" reduces drift potential but cannot prevent drift if applications are not made properly or are made in unfavourable environmental conditions. Models for predicting droplet size are available from Aerial Application Technology Research,[12] and from the Micron Group for rotary atomizers with the Micronair Droplet Size Calculator.

Figure 1. Effect of droplet size on its fall rate or "duty time"

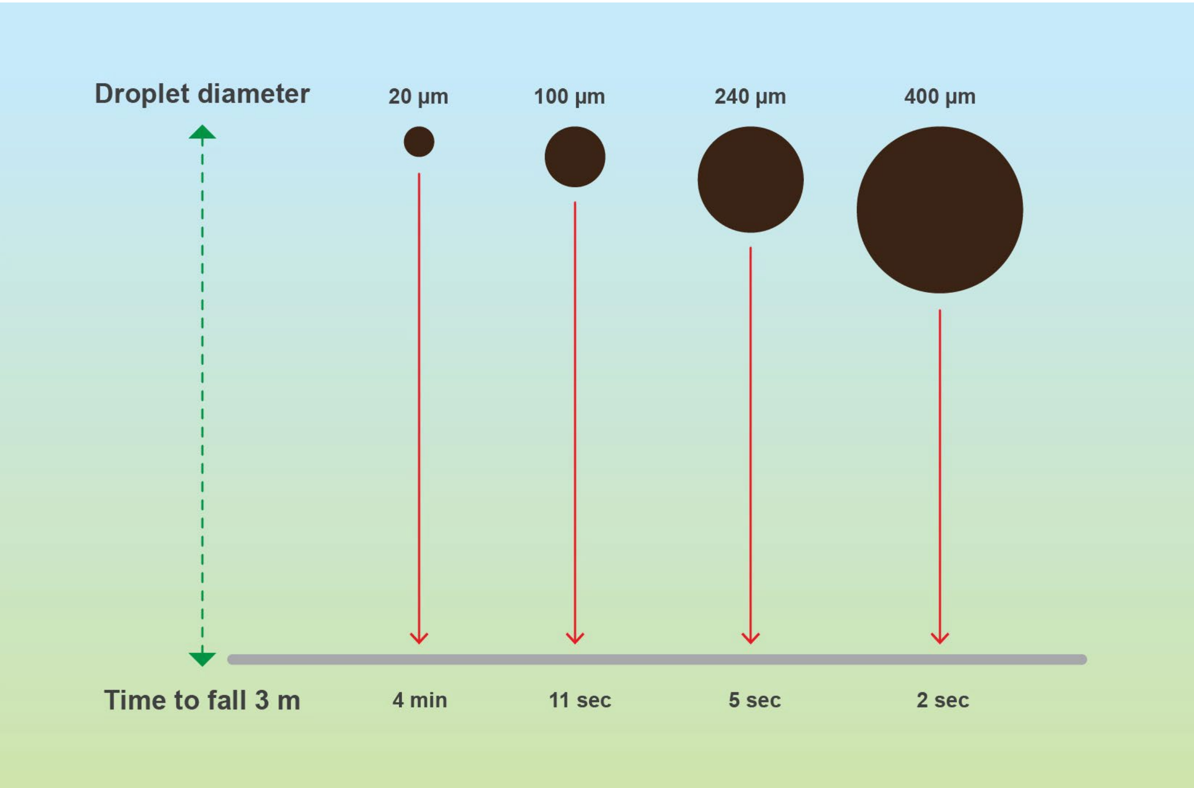


Figure 2. Effect of droplet size on potential off-target movement

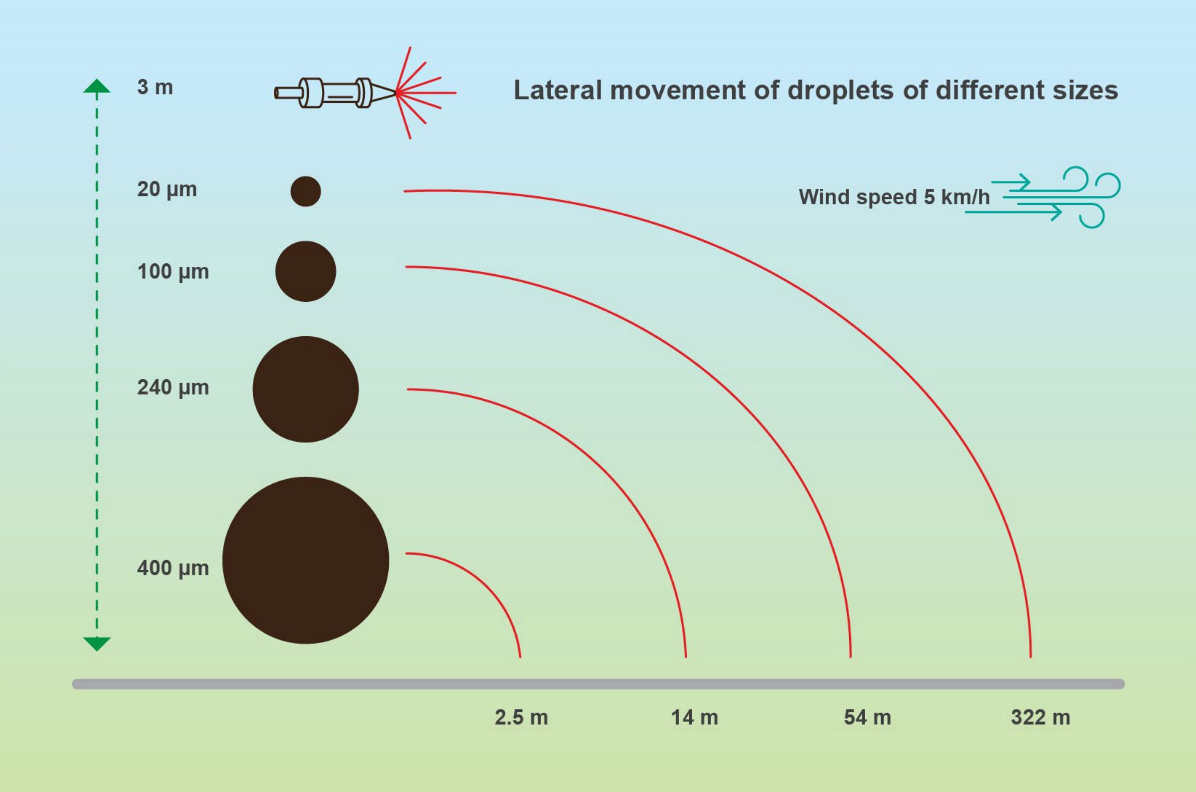
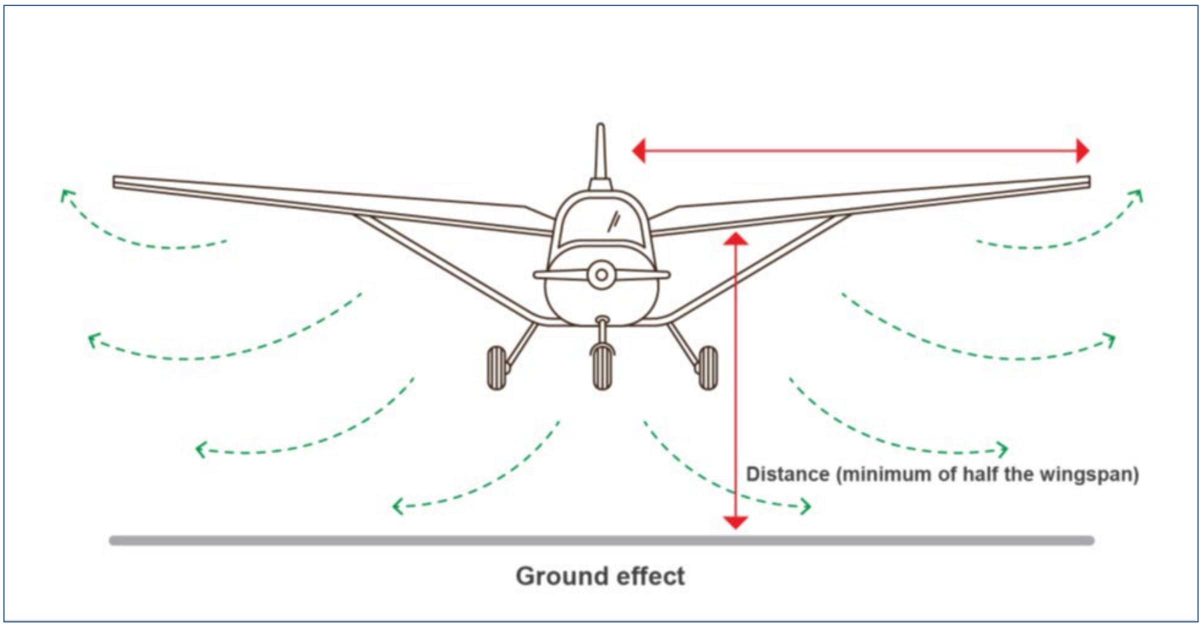


Figure 3. Ground effect of flying too low



Note: A ground effect starts at an altitude of just over one wingspan, but the effect is negligible. A significant impact is typically seen at a distance of half a wingspan height to avoid forced uplifting of air.

Another means of mitigating drift is control of the aircraft's altitude. Flying too high increases the likelihood of spray drift by increasing the distance and therefore the time for atmospheric conditions to entrain droplets. Flying too low may push the spray outwards and upwards, due to a ground effect (see Figure 3) also increasing drift.

The altitude for application should be approximately within one half to three quarters of the wingspan, as heights outside this range can result in poor deposition patterns and increased off-target movement, depending on the aircraft type, meteorological conditions, droplet size and spray system configuration (see Figure 3). To reduce the probability that smaller droplets will be transported in the wing-tip vortices of crewed aircraft, the boom width should not exceed 75 percent of the wingspan of fixed-wing aircraft (see Figure 4) and no more than 80 percent of the rotor width for rotary aircraft.

Research conducted in the United States has shown that reducing the boom length to 60–65 percent of the wingspan of fixed-wing aircraft can further reduce drift by reducing the amount of spray that enters the wing- tip vortices. While a reduction in boom length reduces the effective swath width and therefore the logistics of the operation, it has proved to be useful when spraying near particularly sensitive areas. The USEPA now allows aerial application of most pesticides at wind speeds up to 24 km/hour, with the restriction that the boom length be reduced to ≤ 65 percent of the wingspan for fixed-wing aircraft and 75 percent of the rotor diameter for helicopters. There is currently no recommendation relating to nozzle placement on UASS.

Reducing turbulence can also be helpful. This can be achieved in various ways with crewed aircraft, including dropping the boom below the trailing edge of the wing, shielding obstacles such as flow monitors and piping, and using nozzle drop tubes under the fuselage. Bent boom hangers or blunt surfaces may also cause air turbulence. Aircraft speed is another factor, as flying faster than the recommended operating speed can create excessive air shear at the atomizer, increasing the percentage of driftable fine droplets in the spray. To reduce air shear and the production of fine droplets, the nozzle angle can be adjusted to align it with the air flow (see Figure 5). When rotary atomizers are used, air shear can be reduced at the surface of the disc or gauze by use of air deflector plates. Conversely, flying too slowly can increase turbulence and drift. The vortex strength from an aircraft increases proportionally to an increase in operating weight or a decrease in aircraft speed.

Figure 4. Effect of boom width on spray deposition and minimization of the impact of wing tip vortices

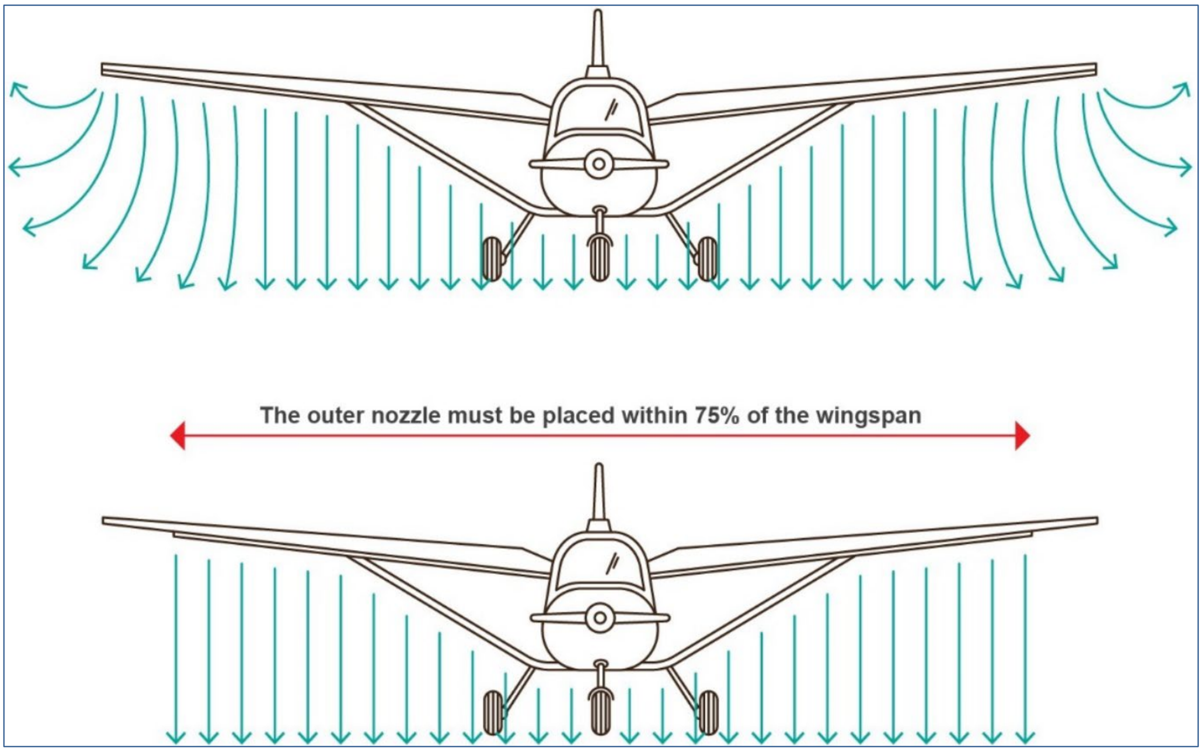
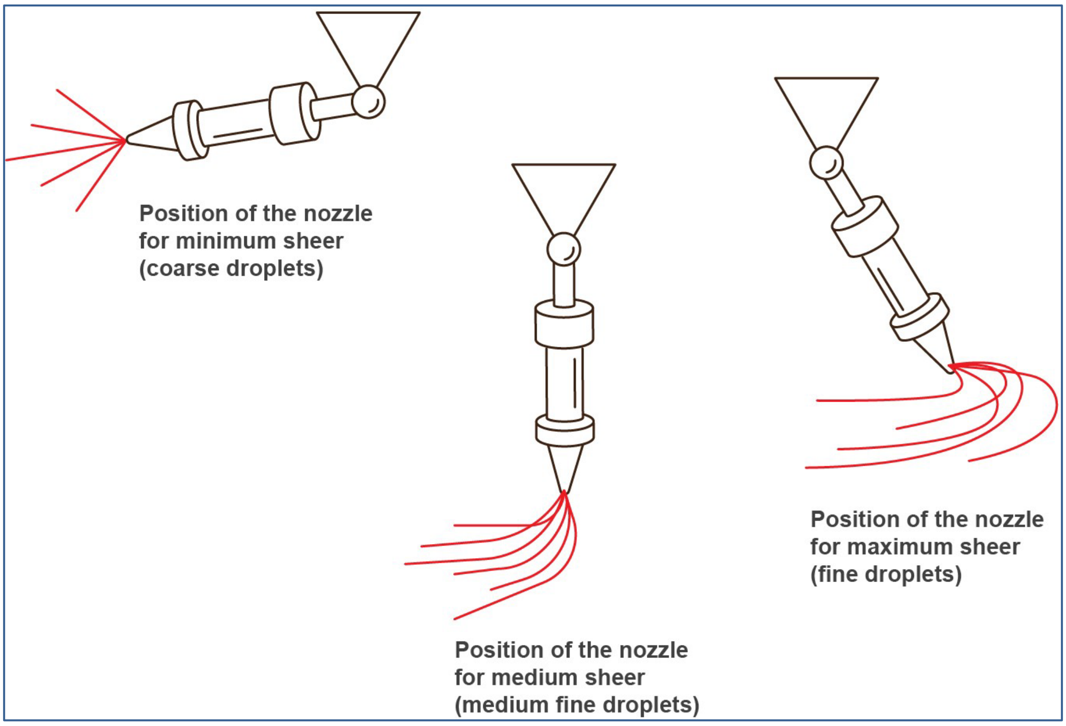


Figure 5. Crewed aircraft: effect of nozzle angle on droplet size distribution



The interaction of equipment- and weather-related factors determines potential spray drift, and the applicator is responsible for considering all such factors when making decisions. General requirements for drift management to avoid off-target movement from aerial applications to agricultural field crops are described below. They are not directly applicable to forestry application, public health uses, or application of dry formulations. Additional specifications should be noted on the label. More stringent regulations in some countries must be observed.

General label language for drift management:[13]

- Volume: Use high-flow-rate nozzles to apply the highest practical spray volume. Nozzles with higher flows produce larger droplets.
- Pressure: Do not exceed the nozzle-directed pressure set by the manufacturer. In general, lower pressure produces larger droplets; when higher flow rates are required, use higher-flow-rate nozzles instead of increasing the pressure. In aerial applications, however, with the nozzle oriented parallel to the air stream, lower pressures produce smaller droplets.
- Number of nozzles: Use the minimum number of nozzles that provides uniform coverage.
- Nozzle orientation: Orientation of nozzles so that the spray is released parallel to the airstream produces larger droplets than downward deflection of the nozzle. Significant deflection from the horizontal will reduce droplet size and increase drift potential.
- Nozzle type: Use the nozzle type designed for the intended application. With most nozzle types, narrower spray angles produce larger droplets. Low-drift nozzles may be used. Solid-stream nozzles oriented straight back produce the largest droplets and the least drift.
- Boom length: In most uses, reducing the effective boom length to less than three quarters of the wingspan or rotor length will further reduce drift. At some point, the reduction in boom length will reduce the effective swath width, but not to the point that application becomes impractical. The benefit is a significant reduction in drift potential.
- Application height: Applications must not be made at a height > 3–5 m over the top of target plants, unless greater height is required for aircraft safety. The recommended height is low enough to reduce off-target losses due to atmospheric inputs and high enough to reduce ground effect and the production of vortices.

- Swath adjustment: When applications are made during a crosswind, the swath will be displaced downwind. Therefore, the applicator must compensate for the displacement by adjusting the path of the aircraft upwind of the downwind edge of the field. The swath adjustment distance should be increased with increasing drift potential.
- Wind: Drift potential is lowest at wind speeds of between 3 and 16 km/hour. Many factors, includingdroplet size and equipment type, determine drift potential at any given speed. Application at lessthan 3 km/hour must be avoided because of variable wind direction and high inversion potential. Local terrain can influence wind patterns. Every applicator must be familiar with local wind patterns and how they affect spray drift.
- Temperature and humidity: When making applications at low relative humidity, set up equipment to produce larger droplets in order to compensate for evaporation, especially when conditions are both hot and dry (see Figure 6). Adjuvants can be used to reduce evaporation.
- Temperature inversion: Applications must not be made during a temperature inversion, because the drift potential is higher (see Figure 7). Temperature inversions restrict vertical air mixing, which causes small, suspended droplets to remain in a concentrated cloud. The cloud can move in unpredictable directions due to the light, variable winds common during inversions. Temperature inversions are characterized by increasing temperatures with altitude and are common on nights with limited cloud cover and little or no wind. They begin to form as the sun sets and often continue into the morning. Their presence can be indicated by ground fog; however, if fog is not present, inversions can be identified by the movement of smoke from a ground source or an aircraft smoke generator. Smoke that layers and moves laterally in a concentrated cloud (under low wind conditions) indicates an inversion, while smoke that moves upwards and rapidly dissipates indicates good vertical air mixing. On-board meteorological systems can be used to detect the presence of inversions throughout application.

Figure 6. Effects of temperature and relative humidity on droplet size reduction and off-target losses

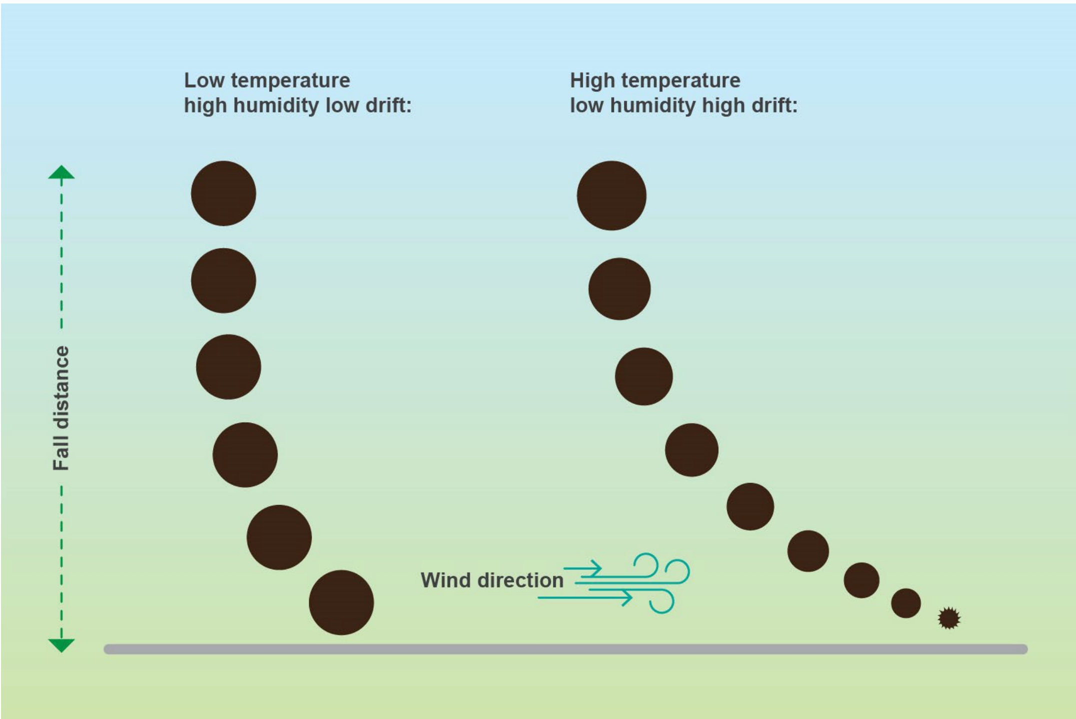
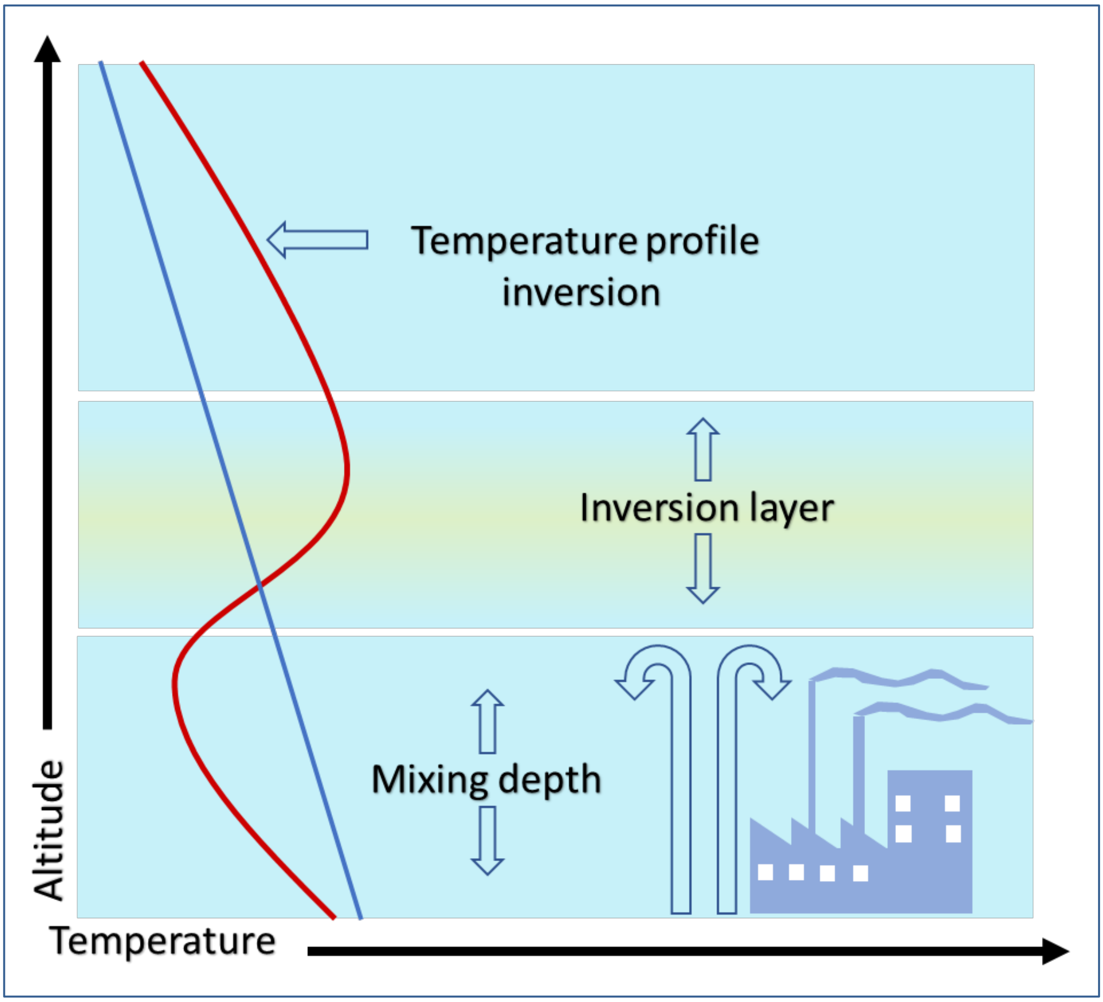


Figure 7. Effect of thermal inversions on movement of the spray cloud



Note: Temperature usually drops with altitude, during stable atmospheric conditions; however, when the surface cools through conduction, the air close to the surface will become colder and denser than the air above it. This causes a density stratification of the air; the cool, dense air can move only horizontally within the inversion, potentially moving a concentrated mass of chemical off target.

- Sensitive area: Pesticides must be applied only when the potential for drift to adjacent sensitive areas (e.g. residential areas, water bodies, natural habitat, threatened or endangered species, non-target crops) is minimal, such as when the wind is blowing away from sensitive areas.

In Australia, Canada and the United States, a mechanistic drift model is used for aerial application, which is publicly available.[5] It comprises two models: the Lagrangian model of AGDISP™, which predicts spray drift of a maximum recommended distance of 800 m downwind from the application site; and the Gaussian extension of the AGDISP™ model, which is used in mosquito control to predict pesticidespray drift ≤ 20 km downwind from the application site. This model can be used in risk assessment of pesticides as part of risk management and regulatory decisions on the use of pesticides. The model itself and more detailed descriptions are available on the USEPA website.[5]

3.2 Operator exposure

In view of the potential danger of aircraft operation, relevant national agencies should ensure a rigorous regulatory and enforcement programme is in place for assessing, certifying, and controlling aircraft and pilots who intend to apply pesticides. Training for certification must include the rationale for preventing health risks for workers and bystanders and systems to mitigate the risk of drift into the environment. Risks to operators should be mitigated by engineering controls and use of appropriate personal protective equipment (PPE).

The risk of operator exposure during application is greatest for backpack sprayers and diminishes with the use of ground equipment without cabs, UASS, use of ground equipment with cabs and crewed aerial application. There are clearly exceptions in each of these use categories.

The role of the pilot should be distinguished from that of personnel involved in mixing and loading pesticides for aerial applications. The pilot is generally not involved in mixing or loading products, and the cabin area is protected from entry of any spray during application. Operator exposure during mixing and loading is typically the highest risk activity in pesticide application. Label recommendations and instructions on use of PPE must be followed carefully, and the safety data sheet for each pesticide being used must be readily available in case of accidental exposure.

The procedures for mixing and loading pesticides for UASS are the same as those for backpack sprayers. The risk is therefore similar, except that the better logistics of UASS may increase the number of loadings per day. In an application by UASS, the operator is separated from the spray, reducing exposure to no more than that of a bystander. The UASS operators are also not at risk of falling or slipping with a full tank during operation. However, operator exposure with UASS may be increased because of the higher concentrations of active ingredient in ULV and LV applications.

Health surveillance is important where required. Effective health monitoring can indicate changes in the health of an individual that can be attributed to a particular pesticide. Surveillance should include health records and medical checks-ups, which can alert medical authorities to any change in health that might be related to exposure during work with pesticides. All workers should be able to discuss their health and well-being at any time.[14]

3.3 Pilot licensing

An agricultural aircraft pilot requires a high level of both ability and training.[15] Use of aircraft in agriculture should be effectively regulated by both departments that control pesticide use and national or regional aviation authorities. As regulations are set by different branches of government, they must be coordinated. Agencies responsible for environmental protection and occupational safety and health should contribute to regulation of aerial application.

Pilots of crewed aircraft must have relevant training and certification to operate aircraft. The pilots of un-crewed aerial vehicles require training, but they are not as specialized and can be operated automatically with GPS, whereby the target is defined, and the flight parameters entered, at which point the operator can press “Go”, and the application will proceed. Many UASS can avoid obstacles; a sensor detects the obstacle and directs the aircraft to hover. When the job is completed, the machine returns, usually to where the flight began. Training is required for safe, effective operation of the vehicles, and the operator should have certification for the specific activity, such as the agricultural aircraft operator certificate in the United States. If certification is not required, un-crewed vehicle pilots can work with the same certification as crewed pilots, with relevant exemptions (e.g. no seat belt required).

3.3.1 Examples of national certification for crewed aircraft

Brazil: The requirements for becoming an aerial operator are regulated by the National Agency of Civilian Aviation (ANAC) and by the Ministry of Agriculture, Livestock and Food Supply (MAPA).[16] Pesticide applicators must also comply with legislation on pesticides, labour and the environment.

- Pilots must have agricultural pilot certification after a flight training course consisting of at least 370 hours of theoretical and practical classes.
- The aircraft must be regulated by the ANAC.
- The agricultural equipment used in the aircraft must be approved by the MAPA.
- Agricultural operators (agricultural aviation companies, farms, cooperatives, agricultural aircraft owners, agricultural pilot education entities) must be trained by and registered with the MAPA.
- Farmers who own agricultural aircraft can operate only in areas that they own or lease.
- All pesticides must be approved for aerial application after evaluation by the Ministry of Human Health, the Ministry of the Environment and the Ministry of Agriculture.
- All aerial operators must follow the rules and restrictions on the label (such as buffer zones to avoid spraying sensitive areas).
- Operators must keep records of each application for a defined time and make them available to the inspection authorities.
- Operators must send a summary of their operations to the authorities each month.
- Any pesticide residues remaining on the plane and from washing and cleaning the aircraft must be disposed of in an appropriate location approved by the MAPA.

European Union: Application of pesticides from aircraft (crewed or un-crewed) is generally prohibited in the European Union. Exemptions are possible if there are clear benefits for human health or the environment and there is no viable alternative.[17] Detailed rules and procedures for the operation of un-crewed aircraft can be found in European Union *Regulation 2019/947*.[18] Most Member States have at least one form of derogation; Germany for example, has one for steep-sloped vineyards.

European Union States that allow application of pesticides by crewed aircraft must meet certain requirements.

- The pilot must have an up-to-date pilot's licence and health certificate.
- Those who apply any type of pesticide from an aircraft must have a certificate and a licence for the category of aerial pest control.
- All aircraft used to apply or dispense any pesticide, fertilizer or seed product must be registered annually with the relevant department of agriculture and must have a certificate of "airworthiness".
- All aircraft must be secured when not in use; that is, kept in a locked building, mechanically disabled from flying or prevented from unauthorized use by any other reasonable method.
- There must be no viable alternatives or there must be clear advantages in terms of reduced impacts on human health and the environment as compared with land-based application of pesticides.
- The pesticides used must be explicitly approved for aerial spraying by the Member State after a specific assessment of the risks of aerial application.
- All pesticides and fertilizers stored and maintained on premises owned or controlled by an aerial applicator must be inaccessible to unauthorized people.
- Aerial applicators must keep records of the pesticide applied, where, by what means, how much and when.
- If the area to be sprayed is close to areas open to the public, specific risk management measures to ensure no adverse effects on the health of bystanders shall be included in the regulatory approval. The area to be sprayed shall not be close to residential areas. The aircraft shall be equipped with the best available technology to reduce spray drift.

United States of America: Aerial pesticide application is common in the United States because of the large size of average farms. The requirements for agricultural aviators are stringent. Details are provided in a circular for 137 certifications.[19] They are summarized below.

- Operators must have a commercial pilot's certificate.
- Private pilots must have a class II medical certificate, to be renewed annually.
- Agricultural pilots must be trained and tested in agricultural aircraft operation, including a test of knowledge and skills administered by the Federal Aviation Administration or the pilots' chief operations supervisor.
- Agricultural pilots must obtain a state-administered commercial pesticide applicator certificate after meeting requirements established by the USEPA and must obtain a licence for each state in which they fly to demonstrate their knowledge in handling and application of crop protection products.
- Pilots must be insured for flying aircraft and for the type of operation.
- All agricultural aircraft must be certificated and registered with the Federal Aviation Administration.
- All pesticides applied aerially must be labelled by the USEPA specifically for aerial application.
- All commercial aerial applicators must keep records of applications.
- All aerial application operations must be conducted according to USEPA worker protection standards.

3.3.2 National examples of certification for un-crewed aircraft

Brazil: Application of pesticides with drones was recently approved in Brazil, in *Ordinance #298*. Operators must meet the requirements defined by the ANAC and by the MAPA, and pesticide application must comply with relevant legislation on pesticides, labour and the environment.[20]

- The pilot must be certified in use of a Class 1 UASS or use of any UASS above 120 m or beyond the visual line of sight.
- Remotely piloted aircraft must be registered with the ANAC.
- Agricultural operators must register with the MAPA.
- Farmers who own agricultural aircrafts may operate only in areas that they own or lease.
- Operators must be aged over eighteen years and have finished a specific course in remote agricultural application, approved by the MAPA.
- The person who coordinates activities must be an agronomist or forestry engineer.
- All pesticides applied aerially must be approved specifically for aerial application.
- All operators must apply pesticides according to the instructions on the label.
- Operators must keep records of each application and make them available to inspection authorities.
- Operators must send a monthly summary of operations to the authorities.
- Leftover pesticides and aircraft washing residues must be disposed of appropriately to prevent environmental damage.

China: Flying a UASS is legal in China, according to the Ministry of Agriculture and Rural Affairs and the national Civil Aviation Bureau.[21] In 2015, the Civil Aviation Administration published an advisory circular, requesting that UASS for plant protection be connected to its cloud system for real-time monitoring of operational data, including, location, altitude and speed. The cloud system can send warnings about UASS that trespass.

In 2017, the Civil Aviation Administration issued regulations on real-name registration of civil un-crewed aerial vehicles that apply to civil UASS with a maximum take-off weight of ≥ 250 g. The regulations require UASS manufacturers to register all product information on the system and require UASS owners to register their names and product information, and place registration labels on their UASS. In 2021, the Certification and Accreditation Administration adopted provisions to promote voluntary certification in order to enhance the quality of plant protection UASS by assessing their safety and performance, with supervision and inspection of factories. Plant protection UASS must meet the following criteria:

- flight height ≤ 30 m.
- maximum flight speed ≤ 50 km/hour.
- maximum flight radius ≤ 2 000 m.
- maximum take-off weight ≤ 150 kg.
- operators capable of reliably monitoring pesticide application.
- aircraft designed for operations in agriculture, amenities, forests, pastures, and fisheries.
- exemption from a pre-fly permit if a plant protection UASS is in accordance with the above designcriteria.
- no UASS flights in prohibited airspaces and no deviation from operational limitations withoutprior approval of the Bureau of Public Security; and
- a licence or proof of knowledge of plant protection by pilots and requisite UASS labelling.
- Insurance is required if a UASS owner applies for an agricultural machinery subsidy from the Ministryof Agriculture and Rural Affairs but is not mandatory otherwise.

Japan: Flying a UASS is legal in Japan, according to the Civil Aviation Bureau.[22] Regulation is based on an amendment to the *Civil Aeronautics Act*, which established areas and flight rules for UASS weighing 0.2 kg as aircraft. A request for approval to fly a UASS must be sought by submitting an application for permission to the Ministry of Land, Infrastructure, Transport and Tourism at least 10 business days before the proposed operation. In Japan, UASS may not:

- fly over densely populated areas or areas surrounding an airport without permission from the Minister of Land, Infrastructure, Transportation and Tourism;
- fly in unrestricted areas above 150 m and fly closer than 30 m to people, buildings, and vehicles;
- be flown over crowds or sites where large groups of people are gathered, such as concerts and sports events;
- be used to transport hazardous items;
- drop objects while in flight, either intentionally or accidentally; and
- fly near crewed aircraft.

Pilots of UASS may fly in prohibited airspaces or deviate from the requirements for operational limitations only with the approval of the Ministry of Land, Infrastructure, Transport and Tourism. There are no restrictions with regard to take-off weight. A licence or proof of knowledge is unnecessary; labelling of UASS is compulsory; and insurance is recommended but not required.

United States of America: The USEPA does not have a finalized UASS policy. Approval of application of pesticides from a UASS is granted by individual states case by case. Use of UASS is allowed when it complies with federal aviation rules, with certification for application of pesticides, and the application complies with labelling for use and safety. Federal regulations applicable to certification of people who handle and apply pesticides are included in the *Federal Insecticide, Fungicide, and Rodenticide Act*.[23] The USEPA and state, tribal and territorial pesticide regulatory agencies enforce the provisions of the Act.

The USEPA regulations apply to the knowledge of the applicator (pilot), including pesticide handling and protection of people and the environment. The Federal Aviation Administration certifies agricultural aircraft operations and enforces *Federal Aviation Regulations* pertaining to aircraft operation. State regulations on licensing, use, storage, handling, and disposal often further regulate application procedures and pesticide uses in order to protect people and vulnerable sensitive areas or organisms. The *Regulations (Part 137)* have been updated to address commercial use of UASS, with exemptions specific to UASS.[19] The UASS may not operate within 5 miles (8 km) of an airport and must operate at a maximum altitude of 120 m at a speed of 160 km/hour.

- The UASS with a take-off weight > 25 kg must have a certificate of airworthiness.
- The UASS must always be in the visual line of sight of the remote pilot. Specifically, UASS must not go beyond a 500 m radius of the remote pilot and 120 m flight ceiling.
- The local flight standards district office certifies pilots.
- Pilots must be of a minimum age of sixteen years, be fluent in English and have passed a test of aeronautical knowledge or already have a crewed aircraft pilot's licence.
- A practical test of forming and uploading, changing in flight, and reporting flight plans is conducted, as is knowledge of handling emergency situations.

3.4 Product selection and registration

Products should be selected after consideration of their efficacy, label restrictions concerning the environment, potential risk of operator exposure, and the recommended dose rates. Understanding the pest's life cycle and the ability of the crop to compensate for pest or disease damage will determine whether pest management or control methods are necessary, and if so, which method should be used. Guidelines may be available in the country or from a suitable crop consultant or biologist. Both, with the applicator's knowledge, may help to identify appropriate products and methods of application.

The products chosen must be applied strictly in accordance with the label specifications. Most pesticide products and formulations approved for conventional aerial spraying are similar to those applied by ground sprayers. When they are applied by air, however, they are generally used at lower water volumes and therefore at higher concentrations of spray solution.

The manufacturer's product label is the main source of information for the user. The label is attached to the product container and usually reproduced on the outer container or wrapper of the transport container. In most countries, adherence to the label recommendations is a legal obligation. The label must not be separated from the container. Many countries now require labels to have quick response (QR) codes that hold traceable electronic information containing a tracking universal resource locator (URL) and an identity document (ID) code, from which the following information can be obtained:

- name of the product and registrant;
- type or status of registration, such as field use pesticide, and safety information; and
- the registration certificate.

The label on the product should comply with national labelling requirements and instruct the user in application of the chemical. Products that are not designated for aerial application should not be used, unless a special use case is made, and an exemption provided by the national authority.

Most labels are not specific to aerial application equipment; there is usually a section of the label that provides direction and requirements for aerial application, which should be read by anyone who uses the product. Some labels may also contain specific requirements of the country to which the pesticide is sold, such as required buffer zones, re-entry intervals and minimum withholding intervals after treatment of harvesting crops. The FAO/WHO *Guidance on good labelling practice for pesticides (Second revision)* provides a review of the preparation and interpretation of labels.[24]

Typical instructions for crewed aerial application are provided by the USEPA.[13]

- Apply spray solutions in properly maintained and calibrated equipment capable of delivering desired volumes.
- Do not apply this product using aerial spray equipment except under conditions as specified within the label.
- Use the specified rates of this compound in 10 to 55 L of water per hectare unless otherwise specified on the label.
- Ensure uniform application – to avoid streaked, uneven or overlapped application, use appropriate marking devices or GPS guidance.
- Do not allow the pesticide solution to mist, drip, drift, or splash onto desirable vegetation since minute quantities of this product can cause severe damage or destruction to the crop, plants or other areas on which treatment was not intended.

Currently, labels are not specific to UASS, and operators follow the instructions for conventional methods. The product label should clearly specify the concentrations and application rates considered to be appropriate and effective.

Because of the high forward speed and therefore flow rate of crewed aerial application, some pesticide formulations may thicken, foam excessively or undergo emulsion inversion. The operator should respect the warnings on the label and consider use of adjuvants identified as appropriate. As UASS usually do not have an on-board agitation system, caution should be exercised in using formulations such as wettable powders and emulsifiable concentrates to ensure that the product does not settle out. Usually, ULV formulations consist of high concentrations of the active ingredient to be used “as is” or diluted with only small quantities of a specified carrier. The ULV formulations, especially on crewed aircraft, are usually limited to mosquito and migrant pest control. The ULV and LV applications are usually used in un-crewed aerial spray systems because of their low payload capacity. Data are being collected on their efficacy and fate.

3.5 Training

3.5.1 Pilots

The pilots for crewed aerial application must hold and maintain a commercial pilot’s licence and a valid medical certificate. There are no medical requirements for the pilots of UASS. Although a flight competence test is not required in all countries, it is advisable that they pass this test. The local civil aviation authority usually administers flying licences and permits to apply pesticides. Additional training in the appropriate handling of pesticides and spraying techniques is usually required to qualify for aerial application certification. All those involved in aerial spray application must adhere to local requirements. Most local authorities require a national aerial pesticide applicator examination for pilot certification, although local municipalities may have additional requirements. The National Association of State Departments of Agriculture Research in the United States has issued a training manual for pilots, which could be used for certification in countries that do not have national training or certification.[15]

An aerial applicator should also sit examinations for one or more categories (agriculture, amenity, horticulture, forestry, and locust and/or mosquito control). A pilot of either crewed or un-crewed aircraft must be proficient in safe, legal, accurate, effective pesticide application from their aircraft. An aerial pesticide applicator must abide by all regulatory requirements and restrictions that pertain to pesticide handling and aerial pesticide application in the country, maintain their operator licences and register individual spray aircraft as airworthy and compliant with the specifications for spraying operations. Both medical and aircraft re-certification should be required annually.

A pilot must prove their competence in:

- judging the appropriateness of a pesticide and the formulation;
- the correct dose rate, application technique and procedures;
- awareness of the hazards associated with use of the product; and
- first-aid procedures in the event of an accident.

3.5.2 Operators and ground support staff

Everyone directly involved in mixing, loading, or preparing pesticides may be referred to as "operators", while those not directly involved in pesticide preparation but in aerial equipment or airstrip preparation may be referred to as "ground support staff". Most countries require that operators follow a code of practice for use of pesticides and be certified in use of professional pesticide products. Safe working practices are necessary to reduce human risk, particularly when storing, handling, and mixing pesticides, calibrating dose levels, using and cleaning equipment, and disposing of waste pesticide.

Protection of mixers and loaders is a priority, as they may be exposed when handling concentrated pesticides. Appropriate PPE should be worn during mixing and loading, and controls such as closed chemical transfer devices, returnable containers and pre-measured chemical dose packs should be used to reduce potential exposure. Training should include appropriate use of chemical loading and transfer systems and also appropriate disposal of empty containers, in accordance with the label. Ground support staff must be trained to ensure that they are adequately protected, that the spray operation is as safe as possible, and to wear the appropriate PPE.[7]

Ground support staff are responsible for meeting legal requirements for operational safety. They are also required to issue warnings to people likely to be near spray operations and to identify no-spray zones to comply with label restrictions. Ground staff can note obstacles such as trees, overhead power lines and areas of concern such as waterways, roads, and residential areas, over which the aircraft may fly during spraying. Ground staff should also be able to identify and contain safe temporary landing zones.

Use of differential global positioning satellite systems for aircraft navigation has almost eliminated the need for flagmen. Pilots of UASS are, however, often (depending on local regulations) required to have an observer. The observer is often the mixer and loader, who is essentially in charge of all aspects other than flying. The observer communicates with bystanders and looks out for obstructions, other aircraft and any potential non-target impact, allowing the pilot to concentrate on flying.

3.6 Communicating risks

If aerial spraying is considered necessary for agricultural or public health purposes, measures should be in place to communicate the potential risks of exposure and how to prevent them.[9] Information on hazards, and risk and prevention of exposure, should be communicated in written and verbal forms relevant for the following target audiences.

- **Pilots and ground support staff:** Before application, pilots and ground staff must be informed about the health risks associated with the pesticides and how to prevent exposure.
- **Mixers and loaders:** Before application, mixers and loaders must be informed about the health risks associated with the pesticides. The recommended PPE must be made available, and its use explained before personnel undertake mixing. The importance of mixing in a ventilated space must also be communicated.
- **Field staff:** Before application, field staff must be informed about the health risks associated with the pesticides. They play an important role in communicating and preventing risks to community members. Field staff should have information about the potential health risks in

the local language, how to prevent them and how long the community should wait before entering the area.

- **Community members:** The public, community members (including farmers, particularly of organic crops) should be told about the risks of aerial application and their prevention before application. Advance warnings of application must be posted 72 hours before application through communication channels used commonly by the communities (e.g. radio, social media, community centres). Communities should be informed of the chemical being used, potential health hazards, how to prevent exposure to spray drift during spraying, and the re-entry period.

In areas where aerial application is used to control migratory pests, signs, notices, and community communication channels should be used to provide information about spraying operations and to warn of the danger of collecting and eating sprayed pests (e.g. quelea birds, locusts). Such applications must be strictly monitored to prevent contamination of community members and the environment.

Labels are an important means of risk communication. The label must be accessible to those who handle the pesticide and must be in the appropriate language. Individuals who will use the label should be trained in understanding the information on health risks and how to prevent exposure of themselves and others. Recommendations on spray drift are provided on the labels of pesticides registered for aerial application, which define the appropriate flight parameters, spray equipment and drift mitigation measures. Spray pilots must observe both the label and local or national legislation regarding the dimension and location of mandatory “no-spray” (buffer) zones. Information on risk mitigation must be communicated to ground staff by pilots and others.

4. Aerial application equipment

4.1 Equipment

Nozzles are probably the most important components of any sprayer. The nozzle type, orifice size, pressure and orientation, determine the droplet size for hydraulic pressure nozzles, while, in rotary atomizers, the important parameters are the design, diameter, rotational speed and flow. In aerial applications, air shear has a significant effect on droplet formation and atomization, particularly at higher air speeds. Aerial nozzles and atomizers should therefore be tested for droplet size spectra in a suitable wind tunnel. The Aerial Application Technology Research Unit of the United States Department of Agriculture has developed several computer models that users can access to learn about the effects of nozzle type and set-up, especially in the production of small droplets.[12] The properties of the spray mix also influence droplet size, and adjuvants are available to reduce the development of fine, driftable droplets.

In the past, agricultural pilots used small-orifice hydraulic nozzles, which were shown to emit drift-prone droplets ($DV_{0.5} < 150$ µm). To minimize off-target losses, larger droplet size distributions are now more typical, with straight-stream nozzles, variable-orifice flood nozzles, large orifice flat fans and drift reduction nozzles. Other common atomizers are rotary or centrifugal-energy nozzles, which offer versatility and droplet size control, with a narrower spectrum of droplet size. These may be wind-driven with the speed controlled by the pitch of the propeller blade or driven by an electric motor with electronic speed control. The electric motor gives the pilot more control over droplet size, as the nozzle rotation is independent of the aircraft's forward speed. Rotary atomizers operate at low flow rates and are therefore widely used for LV and ULV applications. These nozzles do not clog, as small orifices are not required to break up the liquid; therefore, wettable powders and suspensions can be applied more easily. While rotary atomizers can be used in agricultural applications, the high speed of fixed-wing aircraft may make it more difficult to achieve larger droplet sizes.

In agricultural applications, UASS with rotary nozzles and small orifice hydraulic nozzles can be used to create fine and medium droplet sizes. For larger, low-drift droplets UASS, rotary nozzles and small orifice air induction nozzles can be used. The low-capacity pumps found on UASS do not fully atomize large-orifice hydraulic nozzles. Air induction nozzles have two orifices: the first to meter liquid flow and the second, larger orifice to form the pattern. Between these two orifices a venturi is used to draw air into the nozzle body. In the body, liquid pressure decreases, and air mixes with the liquid to form large, air-filled droplets and very few drift-susceptible droplets. These nozzles are not used on crewed aircraft because the high-speed air results in a reduced exit velocity of the liquid jet, which increases the differential velocity between the liquid and surrounding airstream, increasing break-up and droplets < 150 µm. Additionally, the high-speed air across the nozzle prevents proper operation of the air induction ports.

For adulticide applications in public health with the use of a UASS, rotary nozzles are used for ultra-fine aerosol production rather than the high-pressure hydraulic nozzles usually used on crewed aircraft, because the large pumping systems required are not feasible with the constrained payload of a UASS.This will no longer be an issue if improved pumping systems are developed or the payload capacity is increased.

As some pesticide materials are corrosive, all parts of the sprayer that are in contact with the pesticide should be made from corrosion-resistant components. Material compatibility is especially important when undiluted formulations (ULV) are applied, as they often contain high proportions of solvent. The pesticide dispersal system must also resist leaks during the rigours of take-off, landing and flight, as leaks endanger the operator and bystanders, can damage parts of the aircraft, render runways and hangars unusable until decontaminated, and may also harm crops and the environment.

Spray tanks should have a sump that allows total drainage, with a device for jettisoning at least one half of the aircraft's maximum authorized load within 45 s should aircraft safety be compromised. Dump valves are not considered necessary on UASS because of their small tank capacity. Spray tanks should also have a content indicator. Tanks on UASS should be removable to allow proper cleaning. Ideally, tanks should have an agitation system, as some pesticide formulations, such as wettable powders, require agitation to prevent the pesticide product from settling out. Recirculation of all or part of the pump output through a valve that diverts the flow from the spray boom back into the tank (hydraulic agitation) is the commonest method; on some fixed-wing aircraft, an external source is used to power a propeller mounted inside the tank (mechanical agitation). Fine dry materials (≥ 60 mesh) in the aircraft hopper also require mechanical agitation to prevent packing or caking. As most current UASS do not have agitation systems, formulations that will not settle are used.

A pumping system is required to extract the pesticide from the tank. On crewed aircraft, these are usually high-capacity centrifugal pumps driven hydraulically, electrically or by an external wind-driven fan. Pumps should be placed at the bottom of the tank to ensure that they stay primed. The spray system should be calibrated to deliver the desired flow rate and spray pattern or distribution to ensure the intended application rate. This is probably the most important step in application and should be carefully conducted by trained individuals. The purpose of all aircraft dispersal systems is to provide a uniform, metred flow of pesticide through an atomizer to achieve the desired distribution of sprays over treatment areas. Where reduced liquid flow rates are used for ULV spraying, monitoring systems and a flow meter are essential. In-line filters are necessary to prevent blockage of nozzle tips with powders and suspended material.

The spray boom on a fixed-wing aircraft should not exceed 75 percent of the wingspan or 80 percent of the main rotor diameter for helicopters, although some configurations, such as for forest spraying, may require the full boom width to spray vast areas with low-toxicity compounds. The boom width requirements for UASS have not yet been defined and depend on the aircraft design.

The pesticide dispersal system and the materials within it add considerable weight to the platform. Therefore, tests should be conducted to ensure that both crewed and un-crewed aircraft can safely lift off, transport, and apply pesticides when fully loaded.

4.2 Selection of equipment

Every pest situation will have an optimal droplet size distribution for maximum effect and minimal off-target loss. Table 1 provides approximate size range and the associated size classification from the International Standards Organization (ISO) 25358 standard classification.[25] It includes extremely fine and ultra-coarse categories, which provide additional ranges at the lower end, for public health, and the upper end, for low-drift aerial herbicide applications.

Table 1. Classification of droplet sizes

Size classification	$DV_{0.5}$ (µm)
Extremely fine	< 60
Very fine	61–105
Fine	106–235
Medium	236–340
Coarse	341–403
Very coarse	404–502
Extremely coarse	503–665
Ultra coarse	≥ 665

Source: ISO. 2018. *ISO 25358: Crop protection equipment — Droplet-size spectra from atomizers — Measurement and classification.* https://www.iso.org/standard/66412.html

Crop protection: Agricultural applications are generally designed to deposit pesticides on crops at a low altitude in order to retain the chemical within the target zone. The label on the pesticide container defines the required droplet size. For herbicides, very to ultra-coarse droplets are generally used to prevent drift and damage to adjacent crops or vegetation. For insecticides and fungicides, medium to coarse sprays are usually used. Fine sprays provide better coverage but increase the risk of drift, unless it can be controlled effectively.

In general, drift over a large field is of less concern, as long as the droplets reach the target and even distribution is guaranteed; it is at the downwind edge of the field that drift is of concern. In addition to requirements for buffer zones stated on labels, which must be respected, applicators can extend buffer zones, offset upwind, and increase the droplet size distribution to keep the spray within the field boundaries, especially under less favourable spraying conditions.

Forestry: Forestry applications tend to be made at higher altitudes. For application of insecticides and fungicides and for "biorational" applications in forestry, fine to medium droplet size distributions are usually used in order to penetrate the canopy and to target growing foliage. Biological products are often used in forests to minimize adverse impacts on the environment and non-target species; therefore, there is generally less concern about drift. If there is concern, applicators change the last flight line upwind of the downwind edge of the plot. Herbicides are applied on cleared sites in preparation for planting or release from vegetative competition post emergence. As such sites can cover vast areas, aerial application is one of the only viable options, these applications however are conducted once in the lifetime of the forest. To minimize drift, applications of very to ultra-coarse sprays are used at a low altitude.

Public health (vector control): Aerial applications are often used to target insect vectors that transmit vector-borne diseases. Two methods are used in mosquito control: one for flying adult insects, adulticiding, and one for larval developmental sites, larviciding. Adulticiding is conducted with ULV formulations generally at a rate of < 100 ml/ha of insecticide concentrate applied as an extremely fine aerosol with a $DV_{0.5}$ of < 50 µm and a $DV_{0.9}$ of < 100 µm. These very small drops are dispersed over long distances and remain airborne. The technique is often referred to as "space spraying".[26] Larvicide applications, which target mosquito development sites in both urban and wetland areas, are made at an altitude that ensures avoidance of obstacles, with droplets large enough to be deposited predictably. Vectors such as the snail hosts in the schistosomiasis life cycle and the blackfly larvae vectors of onchocerciasis can also be targeted in aquatic habitats. The uniformity of the spray deposit is not as important as in agriculture, as the chemical can be redistributed in aquatic habitats.Application of granular larvicides is common for treating large areas during or before anticipated flooding or rain.

Locust and migrant pest control: In locust control very fine sprays are used, with a $DV_{0.5}$ of 50–100 µm at an application altitude of 5–10 m in order either to deposit the insecticide directly on the insects or to obtain residual coverage of the vegetation they consume. Increased application heights may be used to target flying swarms. When ULV sprays (0.5–1.0 L/ha) are used, the insecticide is mixed not with water but with oil to prevent evaporation. In full coverage ("blanket") treatments, insecticide is sprayed in overlapping swaths, typically 50–100 m apart. In banded or barrier applications, the flight lines are usually 500–1 000 m apart. Barrier treatment consists of treating strips or barriers within the target area to control advancing locusts. A single spray pass from about 10 m in flight height results in deposition of a product in a strip 100–200 m wide.[4]

With the latest mapping and communication technologies, aircraft can also be used as platforms for sensors such as cameras in order to provide real-time information to control centres for rapid decision-making. This is critical during a rapidly evolving migratory pest situation, such as for locusts, when safe, efficient control may be possible for only a few hours a day. Such technology is also useful for interventions in remote or inaccessible areas in order to control populations before they breed or move into inhabited or sensitive areas where aerial application of pesticides is not recommended.

Plantations: Crewed aircraft are routinely used to spray plantation crops such as citrus, banana, dates, and sugar cane, in which aircraft are used because of the height of the crops. Insecticides, fungicides, plant nutrients and foliar fertilizers are applied routinely by aircraft over large areas. The spray practices are similar to those on agricultural row crops, in that nozzles and atomizers are configured to maximize deposition on the crop foliage and minimize spray drift or off-target losses to the ground. As applications are required frequently near local residential areas throughout the year, particular care must be taken in product selection and mitigation of spray drift. Of particular concern in many plantations is protection of water courses, and irrigation and drainage structures that flow through cropped areas.

Un-crewed aerial spray systems: On small holdings, UASS can be used to treat large areas more rapidly than manual back-pack sprayers and other ground sprayers. On farms of < 50 ha, the deposition rate from UASS is similar to that from crewed aircraft sprays, but the area covered per unit time is greater than that with ground-based spraying. In farms of > 50 ha, the shorter flight time of UASS makes it less efficient than conventional ground and crewed aerial sprayers. This can be addressed by the use of several UASS together, in a swarm, with rapid charging and rapid battery replacement, although this increases capital and operational costs. The UASS can also be used to follow high-resolution prescription maps for more effective targeting of spray, potentially treating a larger area with less chemical. Both ground equipment and crewed aircraft can target applications by using prescription maps but perhaps not at the high resolution achieved with UASS spot spraying.

In Europe and the United States of America, UASS must comply with label instructions for crewed aircraft and for ground application equipment. The Organisation for Economic Co-operation and Development conducted a survey of member countries to define aspects of UASS technology that influence risk in comparison with conventional application equipment. The conclusion was that no additional precautions are required as long as label instructions are followed.[27]

4.3 Precision applications

A GPS is essential for precise aerial application. The aerial spraying industry was the first to adopt GPS navigation guidance to improve the accuracy of applications and to assist pilots in aligning spray passes. These systems are now also used to monitor ground speed and automatically adjust the flow of a pesticide to maintain application rates. Most aircraft used in aerial pesticide application are now equipped with GPS guidance, and use of GPS is mandatory in many applications.

The accuracy of GPS guidance depends on the system used, the number of satellites within the view of the receiver and whether ground reference stations are used. The GPS units used for precision agriculture are differentially corrected with a stationary receiver, which transmits signals to the GPS units in its area of operation. Most GPS receivers, especially for UASS, are capable of real-time kinematics, in which the usual signals from global navigation satellite systems are linked to a correction stream to achieve 1 cm positional accuracy. Most aircraft also have internet connectivity, permitting remote access to the system and aircraft tracking. Use of mobile networks is increasing rapidly throughout the world, so that various smartphone and GPS mapping applications can be used on a spray aircraft to capture real-time information on the spray area, including the coordinates of sensitive areas. The GPS can also be used to record the areas treated, the date and time, the products applied, application parameters and the spray track flown.

Precision or prescription agriculture is made possible by combining GPS and GIS to obtain accurate information on position and large amounts of timely geospatial data.[28] While applicators may have treated fields uniformly, they can now micromanage fields with use of prescription maps, which are based on data from crop scouting, soil sampling, yield mapping and multispectral imagery, allowing different rate applications in a treatment area. More precise application reduces waste of product, and therefore costs, and improves yields in an environmentally sound manner. Night-vision goggles ensure accurate timing of application at night and avoidance of non-target species.

Use of aircraft for sensing and monitoring (imaging) provides details of plant vigour or damage. For example, the “normalized difference vegetation index” is a measure of the difference between the reflectance of visible and of near-infrared light from vegetation, which provides an indication of photosynthetic vigour. This measure, with field scouting, can be used to create a geo-referenced map that indicates the type, rate, and location of an applied product. New and emerging technologies developed by companies for precision agricultural imaging allow identification of specific pest types and populations, obviating on-site visits. Prescription maps increase the efficiency of both crewed and un-crewed systems by ensuring targeted, variable-rate pesticide application, reducing the amounts to be applied. Imaging technology is advancing rapidly, providing automatically ortho-mosaiced and geo-referenced imagery for mapping and pest identification. In the future, application maps may be generated in-flight.

Changing rates and droplet size distributions to conform to the maps requires interactive spray systems. The first variable-rate aerial application system was introduced in 2010. Variable rate technologies include simple systems such as a constant rate controller, which monitors ground speed and adjusts the boom flow rate to hold the application rate constant, while other systems include pulse width modulation, which maintains pressure and therefore droplet size while altering application rate. This technology controls the nozzle flow by pulsing an electronically actuated solenoid valve; the flow is changed by controlling the time each solenoid valve is open (duty cycle) at each nozzle.

On-board weather sensors, such as the aircraft integrated meteorological measurement system (AIMMS), provide weather conditions that can be viewed in real time and stored for later analysis and recording. The system also provides data for offsetting spray lines for pattern displacement and potential drift due to changes in wind speed and direction. Thus, flight lines can be adjusted to ensure that spray reaches the targeted area even with displacement of the swath. Use of these technologiescan be optimized by combining them in real time with the spray drift AGDISP™ model, which is used to estimate downwind deposition of spray drift and subsequent swath offsetting on the target and upwind of the downwind edge. Pulse width modulation combined with GPS, AGDISP™ and real time meteorology (AIMMS) creates a system that adjusts the nozzle flow along the boom to compensate for crosswind components during targeted application based on a prescription map.

5. Safety aspects

Once a decision has been made to apply a plant protection product, the safest, most efficacious way must be found for delivering the product to the target. Products should be selected after consideration of agronomic factors, environmental risk, and potential exposure of bystanders and operators. The products chosen must be used strictly in accordance with the specifications on the label. Products that are not designated for aerial application may not be used.

Risk mitigation can include the use of engineering controls and PPE to reduce occupational exposure, safe-handling procedures to avoid spills, timing the spraying for periods when pollinators are not active, and respecting an unsprayed downwind buffer zone to reduce exposure of surface water and non-targeted vegetation. The environmental impacts of aerial spraying may go beyond direct drift to a sensitive area, operator, or bystander to include contamination of water used by local populations and their livestock. Secondary exposure could be experienced by local populations who consume contaminated livestock, birds, or fish. The choice of product, adherence to the instructions on the label and engineering controls should be ensured when highly hazardous compounds are used. The product label provides mandatory use instructions, usually with risk mitigation measures.

5.1 Product transport and storage

Commercial transport of pesticides is usually covered by the country's regulations for transport of hazardous materials, depending on the type of pesticide, the amount, the concentration, and the distance. Safety data sheets should outline standard requirements for transport and storage of products. Applicators may be given special exemption from some regulations when they transport pesticides to or from their property. Under no circumstances must pesticides be stored or transported with foodstuffs. Vehicles must be designated for transporting chemicals. For aerial application, large loading and mixing trucks ("nurse trucks") are often used to refill aircraft at appropriate locations in accordance with restrictions on the label. These are specialized vehicles used for refilling spray tanks and for refuelling during remote aerial applications.

Containers must be checked for leaks and damage and must always remain clearly labelled. This is particularly important for large drums that are stored outside. Storage of pesticides may be covered by local legislation. Correct, safe storage is essential to maintain a safe working environment, to maximize product shelf life and to minimize the risks of fire and spillage. A separate storage facility is recommended for pesticides and similar products. Fertilizers should be kept separate from pesticides, as they are potentially explosive. Separate storage of pesticides ensures that emergency response crews can respond safely to fires and spills. Pesticides should be kept away from equipment, employees, and records.

Large quantities of pesticide might have to be stored and handled at permanent airstrips, particularly for most commercial aerial application operations and for large emergency mosquito or locust control campaigns. The stores must be secure, as they are often remote and unattended. Shade and natural ventilation must be provided for stocks of chemicals. Chemicals should not be stored for lengthy periods outdoors, even in shaded areas, as high temperatures may cause deterioration of both products and packaging, and labels may become unreadable.

Ground support staff must be fully conversant with the procedures to be used in the event of accidental spillage or operator contamination at an airstrip. The airstrip must have fully maintained first-aid kits, an emergency shower unit or adequate water supply, and adequate quantities of absorbent materials to mop up spillage.

Pesticide storage facilities should not be located in a flood zone. Soil and land surface characteristics should be considered when selecting a storage site to prevent contamination of surface water or groundwater. It is recommended that pesticides be stored on raised pallets or on shelves to prevent water damage of pesticide containers or movement off the site in flowing water. Cement or another impervious material should be used for flooring to retain spilled material on the surface. Such surfaces are easy to clean and decontaminate in the event of a release. A floor that slopes into a sump can facilitate collection and containment of a spill. Shelves and pallets made of non-absorbent materials such as plastic or metal should be used for the same reasons. Further information on product storage is available in the FAO *Pesticide storage and stock control manual*.[29]

5.2 Product handling

Spills occur mainly during measuring and mixing of pesticides. The mixing and loading site should therefore be located at least 30 m away from wells, ditches, streams, and other water sources; the pesticide label should be read for more specific instructions. A dedicated facility is required if chemicals are mixed and loaded in one place. Mixing and loading pads consist of a pad containing a sump and a set of tanks to hold pesticide solution. In aerial application, mixing and loading sites may be in remote locations or satellites. Portable, flexible, or inflatable walled, synthetic, drive-over mixing and loading pads are available for such situations, which can be folded for transport. If a pad is not used, it is advisable to move mixing and loading operations frequently to avoid build-up of chemicals from accidental splashes or spills. For any pesticide application, an approved, compatible transfer system for both measuring and mixing chemicals is required, and the system must be designed to handle products of various viscosity and containers with different closure sizes.

Crewed aircraft spray tanks can hold large quantities of product and are raised, so that they are difficult to fill and clean. Closed transfer systems are therefore recommended for filling spray aircraft from ground mixer tankers. A metering system should be available to measure the quantities transferred to the aircraft, so that the pilot has accurate information on the payload. Closed transfer systems prevent the loading crew from being in contact with pesticides and from accidental spillage. Some closed transfer systems empty and rinse chemical containers automatically, eliminating rinsing of empty containers and disposal of contaminated water. Most un-crewed aircraft do not currently have closed transfer systems; however, they are small, and the tank can be filled easily. For UASS that do not have an agitation system, the nurse tank should be agitated with appropriate chemical transfer equipment and PPE before the tank is filled. The product label usually states the requirements for the use of PPE for handling both undiluted (concentrate) and diluted spray solution.

5.3 Management of empty pesticide containers

Local regulations on environmental pollution control must be followed for disposal of empty containers or packaging. Empty pesticide containers must never be reused for any other purpose. In accordance with FAO and WHO *Guidelines on Management Options for Empty Pesticide Containers*, packaging should not be buried or burnt except in an approved, special facility by a hazardous waste contractor.[30]

Empty containers must be thoroughly washed, triple-rinsed and rendered unusable before disposal. Empty containers can be cleaned effectively by hand; the rinsate can be added to the spray tank or be collected in a closed transfer system. Empty containers must be collected and stored securely before disposal and then taken to a centre that is part of a pesticide container management system. Container management is easier for products that are purchased in returnable containers, whereby sealed containers are returned to the manufacturer.

5.4 Accident management procedures

If a pesticide is spilt, the spill must be mopped up immediately with absorbent material or sorbent pads and all bystanders kept away from the contaminated site. The contaminated material used to clean up the spill should be placed in a sealable container labelled as containing hazardous waste. Internal organizations should be notified to determine whether further follow-up or reporting is required. The recommended steps are listed below.

- Notify all relevant parties and contact law enforcement or environmental agencies if there is a risk that surface water was contaminated by the spill or if the spill is too large and cannot be cleaned up immediately. Inform a nearby hospital to be prepared for treating people exposed to pesticides, with a list of the pesticides involved in the accident, with their safety data sheets.
- Immediately remove clothing contaminated with a pesticide, wash in warm water and soap, and warn others of the danger. If there is a fire, do not try to extinguish it without adequate protective clothing and respiratory protection. Keep all bystanders at a safe distance and away from any potential smoke inhalation. Avoid using large amounts of water to extinguish a fire in order to keep toxic runoff to a minimum. Cover powdered pesticides with a tarpaulin to prevent the movement of toxic dust.
- Watch for symptoms of pesticide poisoning, such as headache, dizziness, nausea, sweating or blurred vision, which may occur immediately or after several hours. Records must be kept of all incidents.

5.5 Personal protection and operation and application safety

5.5.1 Personal protective equipment

As pesticide products can be harmful, PPE is essential in any programme. The PPE should be selected in accordance with the recommendations on the label.[7]

Pesticides enter the body:

- dermally or through the eyes during handling, measuring, and pouring concentrated pesticide products and from spray solution during spraying;
- by accidental or deliberate ingestion; or
- by inhalation of small particles or dust during handling and spraying.

Dermal exposure is the most common. People involved in mixing and loading should avoid exposure by using appropriate PPE and following the guidance on labels. Inhalation can be avoided by wearing a respirator or mask, and ingestion can be avoided by storing products safely. Appropriate eye protection must be worn at all times. Dermal exposure of operators during mixing and loading and during aerial spray application can be mitigated by wearing full-length, suitable protective coveralls and gloves. All exposed parts of the body should be washed after work and before eating, smoking, or using a toilet.

Dedicated PPE must bear certification and meet the standards recommended on the product label for each chemical to be handled. The PPE should be comfortable to wear and not restrictive. The PPE remains effective only if it is correctly maintained. Damaged PPE should be repaired to restore it for its original specification; if this is not possible, the item must be replaced. Respirators must be checked regularly,and filter elements replaced in accordance with the manufacturer's instructions. Respirators must fitclosely to achieve a good facial seal and should be tested regularly. Any fault in PPE must be reportedand recorded. Contaminated PPE must be disposed of safely and legally, or cleaned according to the manufacturer's instructions. PPE must not be washed with other personal or domestic items.[7]

Operation of an airstrip also requires safety measures, such as appropriate equipment and procedures for cleaning up spills and a medical kit. Additional PPE for ground crew and field staff includes reflective clothing and ear and eye protection. Water must be available, and appropriate fire extinguishers must be accessible for both the aircraft and the airstrip, with responders competent in their use.

Pilots must wear a crash helmet and approved seat belts and shoulder harnesses in the cockpit and a respirator or fresh-air mask if the few products that require inhalation PPE for pilots are used. No such equipment is required for UASS applicators, although a fluorescent safety jacket and a hard hat are recommended.

5.5.2 Security

Security threats to operations must be prevented, and hazards to the public due to unauthorized or illegal access to the aircraft, or to pesticide materials and equipment, must be reduced. Accepted methods for preventing unauthorized use of aircraft include installing hidden electrical system shut-off switches, parking disabled trucks or other equipment in front of and behind aircraft, removing batteries from aircraft, using devices to lock propellers or rotors, and disabling the engines of unused aircraft. The UASS aircraft should be stored in a locked location. All fuel and chemicals used in operations must be stored securely to avoid both tampering and damage to containers. Security alarm and video surveillance systems are recommended as additional tools to prevent breaches of security.

5.5.3 Flight hazards

Most national aviation authorities impose strict procedures for aerial spray applications in order to minimize risk during flight. Pilots should familiarize themselves with the treatment area and check for obstructions such as pylons, cables, and towers. When possible, the ground crew should be present at the application site to escort anyone on the ground who might be at risk during the application from the area. Emergency plans should be in place for catastrophic events such as failure of an engine or landing gear that would result in a forced landing or a crash. Malfunction of application equipment could include ruptured hoses or lines, a tank leak, pump failure, leaks in nozzle and check valves, and failure of an electronic controller. Any of these problems might result in contamination outside the target area and might require jettisoning a load before the aircraft can return to an airport for repairs.In remote operations, real-time flight tracking systems and designated monitoring personnel must be in place to ensure a rapid response to any aircraft emergency. During applications at night, night-vision goggles should be used, after proper training of pilots in their use.

5.5.4 Local emergency contacts

An accessible list of local emergency contacts must be available, so that, in the event of an aircraft accident, chemical spillage, or environmental contamination, appropriate medical facilities can be contacted with access to poisons information. Local fire departments and other first responders should be informed of the location and contents of a pesticide storage facility. The local chemical product manufacturer or supplier should be listed as a source of up-to-date information on products and on procedures in a plan for handling spills, fire, explosions, and other emergencies. Contacts such as the local civil aviation authority, the water authority, the environmental and pollution control agency, and emergency services should all be listed. A trained local first-aid practitioner should be appointed who is conversant with the chemical products used and with emergency procedures in the event of an accident. They must have up-to-date product labels and safety data sheets and access to a supply of appropriate antidotes for the products used. They must be able to recognize the symptoms of poisoning with the products in current use and to distinguish them from the symptoms of other illnesses, especially those of heat stress.

6. Operational considerations

6.1 Before application

6.1.1 Field survey

Before application, it is essential to visit the target site to identify obstacles, hazards, sensitive areas, habitations, waterways, natural habitats, livestock, and pollinators. This should be done by air, and if feasible, also on the ground. New technologies allow the site to be identified through mapping and operational software; a polygon can then be drawn around the target area and flight parameters defined, which will automatically generate and load the flight lines onto the on-board navigational systems. The applicator must have information on the target size, exact location, current weather conditions, topography, and the location of sensitive areas to ensure the safety of the flight and the spray application, as well as to mitigate drift risk. Chemical trespass and bystander exposure must be avoided. Adjacent crops must be noted, and roads and railways observed, particularly when they are on raised embankments, which may restrict aircraft manoeuvring.

Before application, one of the field staff should make a final check to confirm that there are no recent changes that would put the pilot, other people, property, or the surrounding areas at risk. Communication towers and meteorological towers can be erected rapidly, and they are not always shown on pilot maps; the area should therefore be surveyed to identify any hazards before application.

Agricultural aircraft are highly visible and noisy. As a result, some people view aerial pesticide applications as a nuisance and a concern. It is important to inform bystanders or local communities about hazards before making an application and about requirements for preventing entry by workers or people from surrounding areas. Pesticide labels may require oral notification, field posting, or both (see Figure 8). Warnings must be given in ample time to beekeepers, owners of adjacent crops, livestock owners and those responsible for nearby environmentally sensitive sites if the product label requiresit. Where particularly toxic materials are to be used, it may be necessary to warn emergency services and local environment and water authorities of both application areas and the storage location of the chemical. The product label may give precise advice on the prior warnings that are required, such as how far bystanders should be from the field during application and the length of the re-entry period.

Figure 8. Example of a warning notice of pesticide treatment

Warning: pesticide treated area

Name of pesticide ________________________________

Name of manufacturer________________________________

US EPA registration number________________________________

Application date and time________________________________

Re-entry date and time________________________________

Contact information ________________________________

6.1.2 Spray equipment

The operational readiness of the aircraft must be confirmed before take-off, with confirmation that it is operationally ready and has the power and performance necessary for the application. The maintenance manual of the aircraft and the manufacturer's instructions for the spray equipment must be consulted. The aircraft must have a maximum load capacity that will accommodate the weight of the pesticide, and if necessary, that it can take off from and land on short, rough, or temporary airstrips. The altitude density must also be considered, particularly in warm weather and at high elevations.

The UASS should be inspected before the operation according to the requirements of the manufacturer, and formal spraying should be started only after confirmation that all parts of the aircraft operate normally. Inspection, debugging and calibration should be completed before and after the flight. Theequipment must be appropriate for the pesticide formulation to be sprayed, and the correct application volume, droplet size and spray pattern must be used, as this will determine the efficacy of the application and minimize any off-target movement.

The application volume influences the type of nozzle to be used in an aerial application. The three categories of aerial application volume are: conventional (25 to 70 L/ha or more); low volume (5 to 25 L/ha); and ultra-low volume (< 5 L/ha).

All nozzles should be equipped with check valves to prevent dripping after the spray shut off, in combination with shut-off valves with a suck-back feature. Nozzles, nozzle bodies and check valves must be checked for wear and damage. Rotary atomizers must be in balance and rotate freely. If they are blade driven, the blades must be free of damage and the pitch adjusted for the correct rotational speed. It is important never to exceed the maximum rotational speed as recommended by the manufacturers and a revolutions per minute (RPM) transducer to monitor rotational speeds is recommended. If the rotary atomizers are electrically driven, any electronic controller should be set to achieve the correct rotational speed. All filters must be in place, and valves and couplings clean and serviceable. Hoses and hose joints must be visually assessed, and where component parts are wired to the aircraft, the condition of the securing wires must be checked.

It may not be possible to fully pressurize the spray system on the ground, particularly if the spray pump is wind driven, but the system must be checked for leaks at some stage. The aircraft may have to be in flight to check the operation of the spray system. This should be done with water or another appropriate carrier; dyes can be added to detect leaks.

Electronic equipment such as GPS, flow controllers and mapping systems are important components of dispersal systems and should also be checked for operation. These systems also provide permanent records of the application for environmental and regulatory reporting.

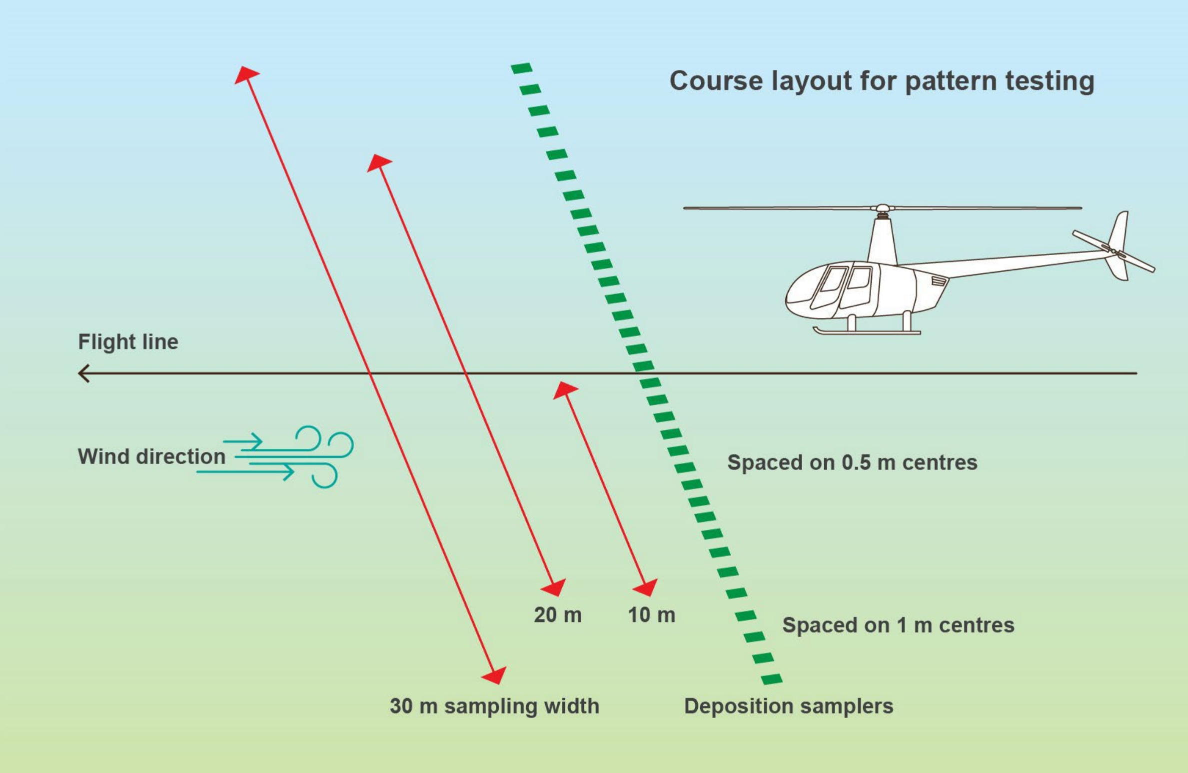
6.1.3 Sprayer calibration

The ministry or agency in charge of agriculture may have a schedule of use guidelines for spray aircraft that include regular spray system calibration and distribution checks and general assessments of the serviceability of equipment. FAO requires its experts to conduct a technical check of the compliance of an aircraft with the requirements of the contract before it becomes operational.

Spray equipment must be calibrated at the start of each season, after equipment repair or if the application technique is changed. The three major factors that influence sprayer calibration are the speed over the ground (km/hour), the swath width and flight lane separation (m), and the flow rate (L/minor g/min).

Most spray aircraft have a GPS system, often linked to a flow controller unit. This equipment provides highly accurate readings of both application speed and flow rate. If the aircraft is not equipped, the forward speed over the ground can be determined by timing the aircraft over a measured distance, flying in both directions to compensate for the influence of wind.

Figure 9. Example of set-up for testing spray swath uniformity



The spray swath is determined by the nozzle or atomizer configuration. A track spacing is selected to ensure that consecutive spray passes allow sufficient overlap of spray swaths for uniform distribution and application rate (see Figure 9). Track spacing is usually determined after assessment of the spray pattern. Flying height should also be monitored during application, usually with a laser altimeter or ground radar interfaced to GPS guidance. The height may require adjustment during application according to the wind speed and direction.

The spray liquid flow rate and droplet size from the nozzles at a given operating pressure and rotational speed can be obtained from the nozzle manufacturer's information sheets and United States Department of Agriculture spray nozzle models. The flow rate should be checked on the ground, if possible, by measuring the volume dispensed over 1 min from each nozzle or atomizer into a suitable collection vessel. Water alone can be used for such measurements if the spray mix consists mainly of water. For ULV applications, the viscosity of the product should be calibrated with the actual material or with a suitable blank ULV product, if available. If it is safer and more practical to use water, a conversion factor appropriate for the density of the product can be used for calibration. The spray liquid output from an aircraft fitted with an electric or hydraulic pump can be determined on the ground, but the aircraft will have to be flown at spraying speed to determine the output from a wind-driven pump system, with the dispensed volume measured by a flow sensor. Flow sensors should be calibrated regularly, minimally before each spraying season. The calibration can be checked for every flight by knowing the exact amount of material released, the time the spray was on, and the application rate calculated from the area covered.

Measurement of the droplet spectrum and uniformity of deposition across the swath is often required, especially in agricultural applications. In agriculture, applicators tend to take their aircraft to an annual "Fly In", where professionals calibrate their equipment to ensure pattern uniformity for calculating appropriate swath width and measure droplet size.

If such services are not available from local experts, detailed instructions can be found in the *American Society of Agricultural and Biological Engineers Standard S386.2*. This standard establishes uniform procedures for measuring and reporting application rates and distribution patterns from agricultural aerial application equipment.[31]

6.1.4 Tank filling and mixing

The pesticide label provides recommendations for tank filling procedures and agitation requirements. The aircraft payload may have to be reduced to compensate for engine performance and airstrip and atmospheric conditions, which determine how much product can be loaded.

Most tanks have top openings for pouring solids as well as quick coupling connection points for pumping in liquids. The closed transfer coupling should have a dry break to eliminate spillage. Gauges or levels that show the amount of material in the tank or hopper are required and should be conveniently located and visible from the cockpit as well as to the loader.

When aqueous solutions are loaded from the top, the aircraft hopper should be filled with half the water before the formulation is added. As spray tank agitation is usually limited, wettable powders must be pre-mixed before loading. Use of a separate mixing system or nurse tank on the ground will accelerate transfer and ensure that the spray mixture is fully agitated before loading. If the agitation is inadequate, phase separation can occur in the spray tank after loading. This is common during flights to the spray area (ferry flights), as the spray pump is secured or turned off. Smaller payload UASS may not have an agitation system, the product is usually pre-mixed in a container, which is agitated before loading and the application made before the chemical can sediment out.

Water quality, particularly hardness and pH, can decrease the efficacy of a pesticide. Application of more than one product at the same time (tank mixing) can improve the logistics and cost of spraying, provided the timing of the respective treatments coincide and the formulations are compatible. If the application requires a tank mix of two or more pesticide products, the labels of all the products must be reviewed to ensure that they are compatible. The directions on each label should be followed, adopting the most restrictive application requirements for mixing and wearing of PPE. The labels should be checked for physical incompatibility, which can result in nozzle and filter blockage, and the nozzle type or filter might have to be changed. A compatibility jar test with agitation should be conducted for new mixtures.

The standard order in which several pesticide types are added to the tank is: 1) water-soluble bag; 2) water-soluble granules; 3) water-dispersible granules; 4) wettable powders; 5) water-based suspension concentrates; 6) water-soluble concentrates; 7) suspo-emulsions; 8) oil-based suspension concentrates; 9) emulsifiable concentrates; 10) surfactants, oil adjuvants; 11) soluble fertilizers; and 12) drift retardants. If dry ingredients are to be used, it is best to add water to them first and then add the pre-slurry to the tank. Box 3 provides a checklist for pilots before application of pesticides.

Box 3. Pilot checklist before application of pesticides

1. Inspect the aircraft and all its safety equipment for proper operation, including the fire extinguisher.
2. Confirm that the correct pesticide material is mixed with the proper amount of carrier in a volume appropriate for the application.
3. Make sure that every pesticide to be applied has a valid label for a listed crop or site and that the label does not prohibit application by air.
4. Read the label information on the hazardous characteristics of the pesticides.
5. Wear an approved safety helmet, long-sleeved shirt, long trousers, shoes, socks, and when out of the cockpit, other required personal protective equipment.
6. Avoid mixing and loading activities to reduce the risk of exposure to pesticides.
7. Ensure that there are no animals, crops, waterways, streams or ponds that might be exposed by direct application or by drift.
8. Avoid spray patterns that would require flying through the suspended spray of a previous pass.

9. Check the atmospheric conditions before application. Do not conduct the application if the wind is stronger than that recommended on the label or if it is too calm, usually less than 3 km/hour.
10. After an application, record any equipment malfunction or problem, and alert other pilots and the maintenance crew.
11. Prepare and keep accurate application records.

6.2 Field application

Proper preparation will ensure spraying under the safest, most effective conditions. The pilot and support staff must recognize the factors and conditions that contribute to off-target pesticide drift and other off-site movements. Ensure that local weather conditions are suitable and remain so throughout the operation. Conditions at an application site may change during an application, and the field staff should watch for changes and potential hazards and maintain open communication with the pilot at all times.

The application site and surrounding areas should be inspected for hazards before the application to ensure that agricultural workers, spectators, trespassers and others, and their vehicles and equipment, are not within or immediately adjacent to the application area, especially down-wind of the site. An aerial spray application must be stopped if an unprotected person enters within a set horizontal distance from the treated area during application. Operators, pilots, and field staff must be vigilant in this regard.

6.2.1 Meteorological considerations

The efficacy of spray deposit is strongly influenced by local meteorological conditions. Wind velocity and direction, stability, temperature, relative humidity, and the likelihood of rain all influence spray deposit. Spray droplet distribution depends on the droplet size, downward velocity, release height and ambient conditions. Vortices created by the passage of the aircraft also influence the spray dispersal. Aerial applications are usually carried out when the surface wind speed is 5–16 km/hour, or in some cases, as high as 24 km/hour. The label should stipulate the minimum and maximum permittable wind speeds.

When water-miscible sprays are applied in high temperatures and low relative humidity, the droplet size is reduced through evaporation, which affects spray drift potential. Spraying should generally not be undertaken under very stable conditions, known as a temperature inversion. Temperature inversions are characterized by increasing temperature with altitude, which creates stable air with less mixing, which can cause spray to move laterally from the target field. Conditions of mild turbulence (neutral stability) are preferable. Unstable air should be avoided for ULV applications and other applications with extremely fine droplet size distributions.

6.2.2 Timing of treatment

The optimum timing of an aerial application depends on the crop condition, pest, or vector species, weed or disease development stage, and diurnal activity, so that the most vulnerable period can be targeted. Treatment timing will also be governed by meteorological conditions. If the timing is accurate, fewer spray treatments may be required. Accurate pest and disease forecasting can be useful in timing decisions.

The most effective spray timing may coincide with the foraging time of beneficial insects. It is therefore important in deciding when to spray to understand the crop, pest development and the status of beneficial organisms. Understanding of the product’s mode of action in relation to crop development stage is also useful for an informed decision of timing. Recommendations for optimal spray timing are generally provided on the product label or by a consultant.

6.2.3 Airstrip operation

The site should be as close as possible to the work area and have good access for vehicles. For remote operations, a plan must be made for safe ferrying of aircraft between the home base, the loading site, and the application site.

A hard apron for loading and washing down aircraft is preferable for permanent airstrips, where spills and washings can be retained and drained into a holding tank for processing. Aviation fuel and pesticide must not be stored together.

Ground staff should load the pesticide into the aircraft to prevent the pilot's contact with the pesticide. The ground staff should be familiar with the products they are handling and with relevant procedures for accidents. Emergency and first aid equipment must be kept in good condition and clearly marked and sited. Facilities for washing and for storing PPE must also be available. Field staff are responsible for site management on the ground. Aircraft used in spray applications should be stored and prepared away from passenger or cargo aircraft operations.[29, 30]

6.3 After application

6.3.1 Warnings after treatment

Immediately after the spray has been applied, warning notices must be posted around the treated area in accordance with any recommendations on the label. Recipients of warnings, such as beekeepers, can be informed that the application has been completed. The field notice should provide the type of treatment and re-entry period. Notices should be removed when no longer required.[14]

6.3.2 Cleaning ("decontamination") of equipment and personal protective equipment

After each use, the application equipment must be cleaned and decontaminated internally and externally. At the end of each day's spraying, the system should be flushed through with a suitable cleaning agent, which is either water and detergent for water-based sprays or a suitable solvent for oil-based sprays. Protective measures should be in place to prevent exposure of staff to the pesticide during these tasks.

Tank cleaning is important, as even very small quantities of residue in a tank can contaminate subsequent spray mixtures, potentially damaging crops. Residues could also affect the compatibility of products in the tank or the toxicity of a subsequent product. The labels on some herbicides provide explicit instructions for tank cleaning. It is better to rinse the tank three or four times with small amounts of water rather than once with a full tank.

Residues of wettable powders can accumulate in the lines and filter housing, and the pesticide product itself or material shed from damaged seals can deposit and build up in un-purged areas, impairing proper atomizer operation.

All PPE must be appropriately disposed of or thoroughly cleaned after use and dried and stored in a well- ventilated store, away from other materials and stored safely to protect people and the environment.

6.3.3 Disposal of surplus spray

Pesticide waste can be classified as surplus diluted spray solution and surplus concentrate material. Planning can ensure that surplus spray solution is minimized by preparing only the amount of product necessary for a given treatment area. When possible, unused chemicals should be returned to the retailer. When this is not an option, an approved service should be used to dispose of unwanted product. Before disposal, unused product should be securely packed and properly labelled (hazardous waste, chemical name, and cleaning mixture name) for transport.

Unused diluted spray and tank washings can cause serious problems, particularly when many aircraft use an airstrip and share mixing, loading, and washing facilities. Thus, a number of chemicals may be washed from several aircraft at the end of work. A dedicated effluent plant or other properly designed, approved, constructed, and operated remediation facility should be used. When there is no dedicated remediation facility, biobeds are considered a viable alternative for disposing of diluted pesticide from tank washings. A biobed could be a 1 m deep pit measuring about 3 m x 6 m filled with a biomix consisting of a mixture of cereal straw, compost, and soil. The biomix absorbs a large amount of moisture and provides an environment in which microbes break down pesticide residues. When used correctly, biobeds can effectively lock in and break down pesticide residues.

6.3.4 Equipment maintenance, repair, and storage

When spraying is completed, the equipment must be prepared for storage as stated in the operator instruction manuals for both the spray equipment and the aircraft. Aircraft-mounted spray equipment is often removed after spraying to release the aircraft for other duties. Both the spray equipment and the aircraft must be thoroughly cleaned and dried before being stored. Aircraft storage will depend on local regulations, but the aircraft should preferably be stored under cover and be fully secured.

Pump drive systems and electrical, hydraulic, or ancillary engines must be maintained in accordance with the manufacturer’s instructions and the spray circuit pipe system fully drained before storage.

All hydraulic nozzles and their filters should be removed and cleaned for storage, and all check valves inspected for damage and wear. The spray pressure gauge must be at zero when the spraying system is not in use. Rotary atomizers must be thoroughly cleaned and checked for damage and balance. Seals must be inspected, and spring-loaded working parts (cut-off valves and liquid restrictor valves) must be working correctly. Magnetic brakes used to stop wind-driven pump and atomizers from rotating during ferrying must be clean and free from contamination and from oil and grease. All electrical components of the spraying system should be checked. When new components are fitted to the spray system or existing ones repaired, all maintenance must be recorded in the aircraft maintenance log.

7. Recording and monitoring

7.1 Field spray records

Record-keeping is mandatory, and local enforcement officers are empowered to inspect records, sometimes up to 3 years after an application was completed. When monitoring of operators' health is mandatory, records might have to be kept for longer. At a minimum, the records should cover all important details of the application, including:

- date (day, month, year) of application;
- time of day;
- wind speed and direction;
- brand or product name of the pesticide applied and amount of active ingredient, with batch number for tracing substandard applications;
- registration number, if relevant;
- application rate in L/ha or kg/ha;
- total quantity of pesticide product applied;
- location of application, GPS coordinates and spray log files;
- size of the treated area;
- name and certificate number of the applicator, type of aircraft and registration number; and
- the equipment used, at minimum the nozzle type, number, and location on the sprayer.

For best management practice, the following additional information should be considered:

- weather conditions at the time of application; air stability, temperature, humidity, wind speed, and wind direction recorded in degrees with a compass;
- any environmental impacts and any adverse effects noted;
- assessment of efficacy;
- application speed and height;
- description of the application site, including type of pest, site or crop treated;
- any change in weather conditions that occurred during the application;
- proximity of the treated area to roads, structures, other crops, field workers, hazards and sensitive sites;
- recent or continuing cultural practices such as irrigation at the application site;
- date and time of the start and end of the application;
- names and amounts of all pesticides and adjuvants applied, and the dilution rate;
- application equipment configuration, including nozzle type, size, spacing, pressure and orientation;
- application pattern and directions in which flight paths were made;
- precautions taken to protect sensitive areas;
- location of the mixing and loading site;
- routes taken for ferrying between the loading site and the target area;
- names of ground crew and people present at the site during application; and
- observations made by the operator, the ground crew or others that may have influenced the outcome of the operation.

All electronic files, including GPS flight data and the associated map files, should also be saved.

7.2 Equipment repairs and maintenance

Repairs to spray equipment must be logged, and changes in spray technique and calibration during the season must be listed for future reference. Information on aircraft maintenance should be recorded in accordance with the requirements of the local civil aviation authority and the appropriate departments of the ministries of agriculture, health, or environment. Required repairs to spray equipment components must be performed promptly, and, when appropriate, their performance should be confirmed, and the system recalibrated. This is usually required to comply with local legislation.

7.3 Surveillance of operators' health

When labels require surveillance of operators' health, a separate record must be prepared for each operator, recording the name, health measures and health history. Exposure periods must be listed, including the date of initial exposure to each product and any recommendations by the clinical practitioner responsible for monitoring. Operators' contact with other chemical products during monitoring must also be recorded. All staff involved in a spray operation should undergo regular health checks. Human biomonitoring is also recommended, involving quantification of each substance and one of its metabolites in a biological sample from a person who may have been exposed. This is not usually done regularly but may be performed after exposure.

7.4 Health and environmental surveillance

Article 4.5 of the WHO and FAO International Code of Conduct on Pesticide Management[2] states that the:

> Pesticide industry and governments should collaborate in post-registration surveillanceand conducting monitoring studies to determine the fate of pesticides and their health and environmental effects under operational conditions.
>
> Monitoring the effects of aerial spraying on human health and the environment is not usually done by application personnel but by a government or state. It is important for detecting and addressing short- and longer-term negative impacts. The aim of environmental monitoring is to determine the fate of pesticides in order to protect the public and the environment from contamination by analysing hazards and developing strategies to prevent pollution.
>
> Environmental monitoring provides the data required for environmental contamination assessments,pesticide registration, pesticide use enforcement and evaluation of human exposure. The commonest types of environmental monitoring are assessments in soil, the atmosphere, and surface and ground water.
>
> The effect of application on the target pest is usually monitored by the entity that requested the application. FAO/WHO or country-specific documentation should be available for each use pattern.

FAO and WHO welcome readers' feedback

FAO and WHO welcome readers' feedback on use of these guidelines. FAO and WHO consider that these guidelines are a living document that could be further improved. They therefore particularly value any feedback from users of the guidelines and welcome any comment. They also value examples of how the guidelines were used.

Please send your suggestions, comments and examples to pesticide-management@fao.org indicating the title of the guidelines and the relevant section and page.

Notes

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The International Code of Conduct on Pesticide Management provides countries with a framework for supervision over pesticides within their territories. The Guidance for aerial application of pesticides provides concise technical guidelines to elaborate specific articles of the Code of Conduct. Targeted at regulatory authorities, operators, and applicators involved in aerial pesticide application, this guidance serves as a reference for making informed decisions and ensuring compliance with national regulations and codes of practice.

Aerial application of pesticides plays a crucial role, especially in agriculture and public health vector control. This guidance addresses the diverse stakeholders involved in aerial spray operations, underscoring the importance of adherence to established protocols to mitigate adverse impacts on human health and the environment. Outlined are the crucial elements for effective and safe aerial application, emphasizing the importance of well-organized operations, trained personnel, minimizing exposure to bystanders, and preventing environmental contamination.

This guidance provides strategies for mitigation, including addressing aerial spray drift, operator exposure, and effective communication of risks. Aerial application equipment is covered in detail, from selection to ensuring precision applications. Different platforms, such as crewed aircraft and Unmanned Aerial Spray Systems are described, as well as technological advancements, including global positioning system guidance and low-drift nozzle technology, that have enhanced precision and safety in aerial pesticide application. Despite concerns about environmental contamination and spray drift, rigorous risk assessment methods and regulatory frameworks exist to mitigate these risks. Essential safety protocols are discussed, covering product transport, handling, and accident management, alongside personal protection and operational safety measures.

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