

DRONES MANUAL

CROPLIFE INTERNATIONAL STEWARDSHIP GUIDANCE FOR USE OF UNMANNED AERIAL VEHICLES (UAVs) FOR APPLICATION OF CROP PROTECTION PRODUCTS.

Executive Summary

Digital agriculture has emerged as one of the most promising technologies to enable sustainable use of resources while satisfying global demands for quantity and quality. Digital tools, such as UAVs, sensors and robotics, are already used by farmers with both large- and small-scale operations to reduce inputs and optimize yields. This will increase flexibility for the farmer when digital solutions are part of the labels of plant protection products.

This document is intended to serve as guidance to farmers and service providers on basic requirements for using UAVs and considering their possible benefits to agriculture, potential risks, the developing regulatory landscape, and challenges to adoption. It then goes on to outline best management practices (BMPs) with UAVs before use, during mixing and loading, as well as during and after application. The content of an emergency plan is considered along with the outlook of the use of UAVs for spraying pesticides.

1. Introduction

The global agricultural drones market is expected to witness a growth of 18.5% compound annual growth rate (CAGR) during the forecast period 2018 - 2026.¹ UAVs offer the potential for addressing several major challenges to global agriculture. With the world's population projected to reach 9.8 billion people by 2050, experts expect agricultural consumption to increase by nearly 70% over the same time period. In addition, extreme weather events are on the rise, creating additional obstacles to productivity.

In response to an ageing workforce in agriculture and the movement of people to the cities, Yamaha Motor company developed the first remote-controlled spraying helicopter in the 1980s and it went onto the market in 1990, since then it has been a substantial success through the benefits it brought to farmers and the regulation system it spurred in Japan. As the UAV market developed in the 2000s, there were many ideas about mapping, crop surveillance and scouting. It was possible to miniaturize recording instruments and as UAV technology advanced, small battery-powered multi-rotor surveillance UAVs started to become available. These developments created many opportunities for improved and customized precision agriculture. However, small UAVs with 2 or 4 rotors were not powerful enough to carry a payload large enough for spraying operations beyond small plots. By 2012, the battery-powered AGRAS 8-rotor emerged. It was able to carry a more useful payload and was backed by very useable software. The Japanese Yamahas were the first spray-UAVs and are the leaders in gasoline powered min-helicopters but the significantly cheaper DJI AGRAS from China has expanded into many global markets. There are new entrants on the market all the time, developing the technology and focusing on a high level of customer service. The development of UAV spraying is tied closely to the development of regulation that wants to support the developing sector but is troubled by nuisance and illegal uses of recreational UAVs that interfere with commercial aviation, have privacy issues and have been

used in terrorist attacks. However, the potential advantages seem to be advancing the regulations and the management of this technology.

Table 1: The uses of UAVs in agriculture

Use	Description
Mapping	Field and pasture mapping may not be available, up-to-date or sufficiently accurate. UAVs are important in establishing and updating the local base-set of geographical information.
Crop surveillance and scouting	Near infrared (NIR) sensors can monitor crop photosynthesis. Data interpreted using Normalized Differential Vegetable Index (NDVI) can be used to determine plant health, water stress, and fertilizer inadequacy as well as pest and disease stress.
Pesticide application	This offers the opportunity for more efficient application in small fields, rice paddies and other water-logged cropping systems, steeply sloping or less accessible areas. There are opportunities to integrate such systems into precision agriculture as the UAVs can be fitted with GPS location and ultrasonic echoing and lasers to maintain the height above the crop.
Irrigation efficiency	Hyper-spectral or thermal sensors used to identify water pooling or broken equipment.
Livestock management	Assessment of the location and condition of grazing animals.

2. Potential benefits using UAVs

The current global population of 7.6 billion is expected to reach 8.6 billion by 2030 and 9.8 billion by 2050, requiring a 70% increase in food production.ⁱⁱ In 2007, the world's population switched from being predominantly rural to being predominantly urban and that trend will continueⁱⁱⁱ. As younger workers leave to seek more profitable employment in cities, an aging workforce is left in rural areas. In developed countries this pattern has been known for a long while but it is increasingly becoming an issue in India and in China^{iv} leading to an increased demand for labor saving, efficient technologies. Spraying from UAVs offers substantial labor-saving opportunities.^v

This rapidly growing area will create new opportunities and questions as it evolves but does offer significant benefits in terms of economics and operator exposure in smaller agricultural units. Though there are no significant differences in the consumer safety profile of produce grown within UAV application, there are significant reductions in operator exposure in small agricultural units which typically use backpack spraying. UAV application, if well managed, could become a key element of Integrated Pest Management (IPM).

2.1 Potential agronomic benefits

There are considerable time and labor requirement advantages for UAVs operating above small rice paddies compared to manual backpack sprayers walking through the water-logged environments to make applications. Comparisons have been made of spray application rates and resulting deposition rates between UAVs, manned aerial spraying, and ground spraying in California grape production. Deposition rates from UAVs were similar to manned aerial sprays but the areas covered per unit/time were in excess of those typically achieved with a ground-based vehicle spraying. It was concluded that UAV spraying could provide a performance that includes beneficial aspects of both systems.^{vi} UAVs are also able to access steeply sloping cultivated areas in some vineyards that are hard to access with ground-based sprayers. They were also noted to reduce the time required to return to the mixing and loading site and to continue spraying.

The use of UAVs for remote sensing and spray application enables variable-rate application and can lead to decrease of 50% in the amount of pesticide applied.^{vii} Though UAVs may not appear competitive with mechanized ground spraying equipment in large-scale row-crop agriculture, UAVs' access to these fields are not limited by wet soil conditions and so offers flexibility. A number of UAVs can be operated together in what is called "swarm technology" to cover a larger area of crop in a short time. Though the technology for this is available, some countries, for example the USA, require modifications to regulatory systems to permit this.

Overall, UAVs are superior to ground-based systems in small- to medium-sized production units, especially if they are in water (e.g. rice paddies) or on irregular or sloping ground. They produce deposition patterns in the crop similar to manned aerial application. UAVs can treat larger areas in the same time compared to manual back-pack sprayers and small mechanical ground-sprayers, also giving advantages in mixing and loading turn-around times. In larger units, single UAV systems are not as efficient as large mechanical ground-based units and can access the land at important times when ground-based vehicles are excluded because of wet soil conditions. However, in units larger than 50 Ha, the relatively short flight time of UAVs makes treatment with conventional ground and aerial sprayers more efficient. This issue may be corrected by using UAVs in swarms, depending on regulatory developments. The use of UAVs for sensing and monitoring in addition to spraying enables variable rate precision agriculture which will lead to increased efficiency through targeted pesticide application and overall reduced amounts of pesticide applied.

2.2 Potential user benefits

The procedures for mixing and loading UAVs are the same as for backpack sprayers and so in comparison, there is no enhanced or decreased risk of this operation. Application by UAV separates the applicator from the actual spray application and as a result, reduces the applicator's exposure exponentially to no more than that of a bystander, around 2-3 orders of magnitude less.^{viii} UAV operators will also not be subject to the risk that backpack sprayer applicators have of falling and slipping with a full tank during operation.

2.3 Reduced drift potential

At present, there is some uncertainty as to whether the drift potential from UAV use in spraying compares to backpack sprayer use, mechanized ground spraying, application through irrigation equipment, mist-blowers or aerial application. Drift data needs to be analyzed and guidance provided with reference to formulation and nozzle type. Though aspects such as height above the crop, speed and pressures may be similar to backpack sprayers, drone rotors create vortices that can create air flow patterns that can enhance the drift potential. The use of pesticides through low pressure irrigation systems does not create a particular risk of drift, but high-pressure systems and end-guns on irrigation equipment can create a substantial risk. It is unlikely that UAVs will create as much drift as these systems. Similarly, mist-blowers typically make applications of fine particles prone to drift upwards and can create a potential issue. It is unlikely that UAVs will create more than this. Conventional aerial application is typically done at a greater height and speed than UAVs and would be expected to result in greater drift. Helicopter rotors will create more powerful vortices than UAVs and so overall, UAV drift potential would appear to be less than from all forms of conventional aerial application. It is expected that UAV drift potential would be greater than with backpack sprayers, equal to slightly greater than mechanically propelled sprayers but less than found with high-pressure irrigation systems, mist-blowers or aerial application with aircraft or helicopters. Information is being gathered world-wide to quantify these assumptions. It is recommended that low-drift nozzles are used with UAVs. Drone applications will also have to comply with local regulations. For example, in the Netherlands all applications can only be made with 75% drift reducing nozzles or technology

2.4 Precision agriculture and reduced pesticide use

If field maps are not available, up to date or sufficiently accurate, UAVs are important tools in establishing and updating the local base-set of geographical information. This is the base data-set which much precision agriculture depends upon. Once this is established, checked and calibrated or “ground-truthed”, it can be used with sensing or monitoring equipment fitted to a UAV and the appropriate computer-based software to interpret the data that has been gathered. Near infrared (NIR) sensors can monitor crop photosynthesis. Data interpreted using Normalized Differential Vegetation Index (NDVI) can be used to determine plant health, water stress, fertilizer inadequacy as well as pest and disease stress. Hyper-spectral or thermal sensors can be used to identify water pooling or broken equipment. These systems enable targeted application from a UAV and an overall reduction in the amount of pesticide applied.

3. Potential risks of using UAVs

Flying UAVs with spinning rotors can present a potential physical threat to those not involved. To date, most incidents tend to be associated with the use of drones for photography at public events where many people are gathered. This is less of an issue with agricultural drones that are typically used away from communities. Other general concerns with UAVs involve the disruption of aircraft activity, invasions of privacy, smuggling drugs, etc. into prisons and even use as weapons ^{ix}.

3.1 Environmental exposure

Off-target drift is a potential source of exposure to bystanders, residents and operators on the ground near the application site. The comparative magnitude of the drift is considered in more detail in 2.3. It is expected that drift from UAV applications will be within the parameters of other existing methods and so similar precautions would be taken to protect bystanders and nearby residents from drift from UAV applications.

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3.2 Equipment contamination

UAVs can become contaminated with pesticide when in storage, transport, mixing and loading, use and emptying. All of these routes of contamination are similar to those of other, small application equipment. Because of the vortices created while flying drones, it is inevitable that some of the spray material will be drawn into the rotor system and will result in deposition on the UAV. After use, particular care needs to be taken when handling the equipment and attention must be paid to cleaning it and also to the fate of the cleaning water and other materials, so that further contamination is not created. Mixing and loading contamination should be of a similar concern to other uses, such as backpack spraying equipment. Effective cleaning also eliminates the cross-contamination of the spray liquid from a previously applied product.

3.3 Crop safety

Off-target movement of spray drift from UAVs into adjacent cropped areas can run the risk of damaging the foliage, productivity and fruiting potential of some crops, depending on the material used. This can be mitigated by existing protections based on the materials used, nearby crops and the estimates of UAV drift potential discussed in §2.3.

3.4 Interference with operator control

As UAVs typically use un-encrypted control signals, there is a chance of the system being hacked.^x Though this is not major problem for spray-UAV users, the chance of misuse exists and can be protected against.

4. Regulatory aspects

The use of UAVs in agriculture is affected by regulations related to pesticide use and also to aviation. Such regulations come from different branches of government and need to be coordinated. Thoughts on policy issues for UAVs in agriculture are summarized by FAO in Sylvester (2018)^{xi}- UAVs are usually categorized as < 2 kg, < 25 kg and > 150 kg, the latter being considered an aircraft. Risks are seen to increase in the order remote < urban < high-capacity airspace. At present, rules are under development, for example, by the European Remotely Piloted Aircraft System (RPAS) Steering Group, the Drone Advisory Committee in the US and the Swiss Office of Aviation. These authorities take a risk-based approach to managing the avoidance of people, infrastructure, natural obstacles and other vehicles. If a UAV is to conform to the visual line of sight (VLS) aviation conventions, then the UAV must not go beyond a 500 m radius and 120 m flight ceiling compared to the position of the operator. In many agricultural uses, there is a demand to go further than this, beyond line of sight (BLS) operation in large fields and extensive agriculture. Here, there must be a risk-based assessment of the avoidance of the collision hazards noted above. Regulations are evolving and it is important to get alignment among stakeholders.

4.1 North America

The growth of drone use has been substantial in the USA. Aerial spraying is widely used and so drone use, in general, lies within existing use patterns. Restrictions outlined under FIFRA and the relevant state agencies for aerial spraying also apply to the use of UAVs.

The US Federal Aviation Agency (FAA) adopted a rule for drones weighing less than 55 pounds (25kg). According to this rule, a process for obtaining certification as a remote pilot in command (Remote PIC) is introduced and will apply to those who operate UAVs for commercial uses or incidental to a business, such as in agriculture. Therefore, farmers who want to use a drone on the farm need to understand and comply with these provisions. In the USA, UAVs must not be flown 400 feet (120 m) above the ground and it is advised for users to file flight plans with local airports or the FAA before flying.

The FAA regulates UAVs under Part 107 of the Small UAV rule and under FAA Regulations PART 137—Agricultural Aircraft Operations. These regulations address the UAVs in commercial operations, the pilot and chemical handling. Part 137 has been updated to address issues with UAVs that are separate from conventional aircraft, e.g. the mandatory use of seat belts. Operating bans for USVs cover within five miles of an airport, maximum altitude of 400 ft (122 m) and speed of 100 mph (161 km/h). UAVs with a take-off weight of <25 kg do not need an airworthiness certificate, but several leading models have been granted them. Then UAV must always be in the visual line of sight (VLOS) of the controller and only flights in daylight are allowed.

The pilot must be certified by the local Flight Standards District Office (FISDO). This will require a minimum age of 16, English language fluency and passing an Aeronautical Knowledge Test or owning a pilot's license. A practical test of forming and uploading, changing in flight and reporting flight plans will be assessed along with knowledge of how to handle emergency situations.

Chemical handling is covered by an Air Applicator's License from the relevant state or in some cases county agricultural department.

The use of drones for spraying was cleared in Canada in July 2017 when Transport Canada issued its first approval for commercial spraying with an UAV. To fly any aircraft, manned or unmanned, for commercial purposes in Canada, one must first obtain a special flight operations certificate or SFOC.

4.2 Europe

Though mapping and surveillance drones are widely used in Europe, pesticide application via UAVs is considered aerial application and is allowed only in special circumstances. Though livestock surveillance is more suited to extensive agriculture in, for example, Australia, this is increasingly used as well. Large civilian UAVs exceeding 150 kg are regulated by EU law and monitored by the European Aviation Service Agency. Smaller UAVs, of the type most used in precision agriculture, are regulated by national rules based on the principles agreed in the frame of the 2015 Riga Declaration on Remotely Piloted Aircraft.^{xii} UAVs with a weight of <150 kg are regulated by member state rather than EU legislation, leading to national differences. However, the application of pesticides with manned or unmanned aircraft is generally prohibited in the European Union because of concerns about the drift of pesticides. Exemptions are possible if clear benefits for human health or the environment can be demonstrated or if there are no viable alternatives according to the sustainable use of Pesticides Directive, 2009/128/EC. Some exemptions have been given in Germany.^{xiii} In Switzerland, which is not part of the EU, clearance was given for the use of UAVs in crop spraying in July 2019^{xiv}. Spraying of vineyards is of particular interest.

Because of the disruption caused around Gatwick and Heathrow airports in early 2019 and late 2018, the UK government decided to extend the area around airports and runways in which UAVs are banned from being flown. As of March 13 2019, it became illegal to fly a drone within 5 km of an airport compared to the previous limit of 1km.^{xv}

4.3 Latin America

Overall, the use of commercial UAVs in Latin America is still low compared with China, Europe and the US. In Latin America. Crop-spraying drones are being used to augment aerial spraying and Uruguay, Argentina and Brazil are enacting flexible regulations to allow this. Uruguay was the first country in the region to have a specific state policy with regard to UAVs. The extremely large rows-crop fields in Brazil tend to make manned aerial spraying and the use of large self-propelled rigs more economic.

4.4 Asia Pacific

Regulatory aspects of UAV application are well established under civil aviation and pesticide use regulations and licensing in Japan and South Korea. Aviation rules and draft guidelines are in place in China, Taiwan, Malaysia and the Philippines. Flight standards are in place in Thailand, Indonesia, Vietnam, Bangladesh and India but draft product use guidelines are not. There are no rules or guidelines in Pakistan.

4.5 Africa

UAVs are becoming a significant technology in some outlets in Africa. In South Africa, in late 2019, the use of the first UAVs for spraying was approved under aviation and agriculture regulations. The African Union is looking into establishing operational and regulatory guidelines.

5. Challenges for UAV technology adoption

At present, agricultural spray drones come as gasoline powered mini-helicopters and battery powered 4, 6 or 8 multi-rotor UAVs. The helicopters are the most established and expensive, carrying 16 to 30 l of spray material. Multi-rotor drones are cheaper, can carry 5, 10 or 15 l but typically only fly for 12 – 15 minutes. Heavy lifting UAVs are under development but will require changes in regulatory structures to allow them to fly.

5.1 Mini helicopters

These were first developed in Japan by the Yamaha Motor Company and include the RMAX, the Fazer and Fazer-R. They have a two-bladed rotor, two or four stroke water-cooled gasoline engines and are remote-controlled by a line-of-sight user. Though originally designed for precise aerial spraying of crops, they have also been used for aerial surveys, reconnaissance and disaster response. These helicopters can carry between 16 and 32 kg of spray liquid or granules and have a typical flight time of around one hour.

5.2 Multi-rotor UAVs

The majority of these are currently designed and built in China. The best known is the DGI AGRAS MG-1, an 8-rotor UAV with a payload of 13.7 kg. The AGRAS is battery powered but has a shorter flight time than the helicopters, at around 15 minutes. This model is well proven in the field and is widely used both in and outside China by contract sprayers either as a single UAV or in a swarm with others.

A slightly different approach is used by the Thea 140. This 4-rotor UAV carries a 10 liter payload and has a hybrid (gas/battery) power system.

Chinese online sellers offer at least 60 different 4 and 6 rotor battery-operated spray UAVs with payloads of 7 to 10 l, flying for 12-15 minutes at a time, but these have limited penetration of the market outside China. Similarly, there are at least 10 generic 8-rotor type spray UAVs.

There are now some US-made and serviced UAVs. Like the HSE M6A Pro 15, a US-made 6-rotor UAV with similar specifications to the DGI AGRAS MG-1.

5.3 Heavy-lifting UAVs in development

In development is the Carrier HX-8 which can take 20 liters but is not yet available on the market as a spray drone. The Airboard Agro 100 is a 100 liter UAV being developed in Latvia. The Tactical Robotics Cormorant is a 500 liter UAV being developed in Israel. Originally intended for delivery and rescue operations, this UAV is powered by a turboshaft gas turbine. It is still in the design stage and will require a revision of legislation to be used in spraying operations.

5.4 Affordability

At between \$1,500 and \$20,000 for most commercial grade battery operated multi-rotor models, UAVs are an affordable investment when compared to most farm equipment, often paying for themselves in a single season. The use of scouting UAVs allows higher resolution data of crop conditions (up to 16x) compared to traditional satellite methods, quick identification of stressed areas, pest and disease infestations and true plant counts.^{xvi} Estimates show that in fields of up to 50 ha, UAVs can apply up to 5 times faster than conventional equipment^{xvii} and by focusing only on areas needing treatment as revealed from crop monitoring, savings of up to 60% of materials may be made.

5.5 Supply and training of pilots

There is a ready supply of UAV pilots drawn to this new technology but fewer that have an understanding of the proper use of chemicals. In many countries, there are complex licensing laws and exemptions that apply based on the total weight of the UAV and its use in spraying operations. Training is provided by the larger UAV manufacturers and in some cases by state or state authorized institutions.

5.6 Restrictions for UAV swarms

While most spraying is carried out using single UAV units to either patch, strip or spot spray, rapidly developing technology may enable much larger areas to be sprayed in the future. UAVs are already capable of communicating with each other to avoid collisions and to fly in formation. This could allow a string or swarm of UAVs to apply pesticide across whole fields. While trials are under way, the main obstacle to success could lie in legislation with governments and military officials wary of terrorist threat presented by a swarm of unmanned aircrafts. Some derogations have been given in the US but at the moment, this is being done on a case-by-case basis.

5.7 Crop limitations

UAVs are suitable for most crops grown outdoors and are particularly useful in small fields and in water-logged conditions, for example rice. The use in vineyards is also interesting as world-wide there are many small plots that are grown on steep slopes that are difficult to access for many vehicles and often require specialized wheeled vehicles that are more expensive than UAVs. Penetration of spray mist into the canopies of tree-crops is normally achieved by ground-based equipment with pressurized blowing equipment which results in enhanced potential for drift. Whether UAV applications can achieve the penetration needed for this outlet is as yet unresolved.

UAVs are competitive with manual backpack spray equipment in all outdoor outlets, significantly reducing the potential for operator exposure and increasing the area that can be treated. There are potential efficiency advantages with UAVs in spot-treatment for vector control and Right of Way vegetation control, however in fields of > 50 ha, conventional ground and aerial applications will be quicker than single UAVs. The challenge will be to work out the economics of UAV-swarm applications if they are permitted on a wide scale. Recent developments in the use of drone-swarms in terrorist attacks in the Middle East have led to concerns about the wider adoption of this technology which at present tends to be addressed on a case-by-case basis.

5.8 Weather conditions

Spray deposit efficiency is greatly influenced by local meteorological conditions at crop height. Wind velocity and direction, temperature, relative humidity and the likelihood of rain all influence spray deposition. The distance a spray droplet travels depends on the droplet size and downward velocity, the release height and the ambient conditions. Vortices created by the UAV will also influence spray distribution efficiency, though they can also contribute to drift in some circumstances.

Aerial spraying is normally carried out when the surface wind speed is less than 6-7m/sec which is a safe speed for aircraft handling and safety. UAVs are considerably lighter than spray aircraft and may suffer problems at wind speeds in excess of 3 m/sec. The optimum speed of application for most multi-rotor UAVs is around 6 m/sec and an upper limit of 8 m/sec. Wind speed and direction will also influence flying height. When the wind speed is less than 3m/s, a boom height of between 2 and 3 m above the crop will ensure good lateral movement of the spray. Application at 1.5 m can be less efficient due to the turbulence created^{xviii} but flying height must be reduced if the wind speed exceeds 3m/s. Applications of greater than 4 m above the crops seem to be less efficient.

5.9 Equipment malfunction or human error

Comprehensive pilot training and certification should address such instances. In the event of loss of connection with the pilot, the operator should know what the UAV's programmed procedure is, usually, stopping, hovering and marking its position on GPS or landing. Though local rules may differ, typically UAVs should be no more than 120 m above the surface over which they are travelling and should generally leave 120 m horizontal space between any obstruction in their path. In the event of a catastrophic failure due to equipment malfunction or bird-strike, the operator should have a clean up and recovery plan already prepared and available.

5.10 The design formulations for UAV application

Formulations registered for use in UAVs must be the only ones used. Ultra Low Volume (ULV) formulations applied through ULV nozzles are the obvious choice if available. This helps to address the limited flight time for UAVs and to make the application most efficient. In reality, there will be instances where regulations are not so prescriptive and it is therefore important that the nozzles used are appropriate to the formulations.

6. Best management practices (BMPs)

Here the BMPs before, during mixing and loading, during application and after application are considered.

6.1 BMPs before application

6.1.1

6.1.1.1 *Read the label*

Whenever handling and applying pesticides always read and understand the label before use and follow the instructions.

6.1.2 *Storage and transport of pesticides*

Pesticides should be kept in a secure, locked place to which children, animals or unauthorized people do not have access. They should not be stored in living or sleeping quarters and should be kept separately from all food, including animal feed, and away from water and water supplies. They should be kept dry and out of direct sunlight and excessive heat or cold. Pesticides storage areas should be away from naked flame or equipment that generates sparks. Storage places should be well ventilated and bunded or otherwise able to ensure the containment of spills. Pesticides should never be transferred into containers other than those in which they were supplied.^{xix}

The quality of the pesticide packaging should be adequate for the distance and type of journey that has to be made to the spray site. Never transport pesticides in the passenger area of a vehicle; instead, place them in the trunk or truck-bed. Do not bag pesticides with groceries or other household items, or carry them in the same area of a vehicle to avoid accidental contamination. Make certain pesticide container lids are securely fastened. Secure containers in an upright position to ensure they cannot fall or be knocked over. Boxes and other packing materials may be useful. Protect pesticides from extreme hot or cold temperatures. Temperature extremes can damage containers and cause chemicals to lose effectiveness. Never leave pesticides unattended in an unlocked trunk or open truck bed to prevent contact by children or others.^{xx}

6.1.3 *Flying conditions and itinerary*

- Check the weather and temperature. Most UAVs are not suitable for flying in precipitation, windy days, and freezing temperatures.
- List the areas to be treated, the products to be used, rates, etc.
- Have maps of the surroundings to hand including buffer-zones for sensitive areas, housing, schools, playing fields, hospitals or medical facilities, gardens, roads, restaurants, etc. where bystanders may be present. Be aware of the location of livestock in nearby fields.
- Note the location of water bodies, wetlands or other environmentally sensitive areas.
- Be aware of the presence of beehives and adjacent crops in bloom with bee activity.
- Record any nearby shrimp or fish-culture or silk production sites.
- Note any sensitive non-target crops adjacent to the sprayed area, including organically farmed fields.

6.1.4 Know and comply with the relevant laws

Be aware of and comply with all the rules that apply to the use of UAVs to spray crops, public health pests, Right of Way maintenance, etc. in the area in which you will be operating.

6.1.5 Necessary documentation

All the documentation should be up-to-date and stored securely in an easy to access place. Any documentation that needs to be taken to the field should be held securely in a waterproof covering and returned to the secure long-term store after spraying. The documentation may include;

- UAV registration or license if required.
- Pilot operational license and chemical handling licenses.
- Pest control licenses when conducting aerial spraying activities on a commercial basis.
- Records of the names, and relevant qualifications of assistants and other crews involved in the spraying activity.
- Records of what was done during the spraying may also be required.
- If flight plans are required, these should be securely stored along with any specific clearances that were necessary.
- Any waivers that are required.

6.1.6 UAV fit for flight

- Carefully go through the manufacturer's preflight checklist and check every part to see any signs of damage or obstruction.
- Ensure that batteries and reserves are adequately charged, and that battery charging equipment is available if required.
- Check functioning, controller, etc.
- If the UAV is hybrid or gas powered, ensure that there is sufficient fuel in a container safe to store and transport.

6.1.7 Firmware

- According to the manufacturer's instructions, check the UAV firmware - it is essential to upgrade the firmware as upgrades are made available.
- Ensure that your UAV is always calibrated in terms of connectivity, navigation, and behavior. Check preflight settings e.g. GPS, compass, LED status; satellite locks, gimbal level, flight controls.
- Older UAVs used in mapping should be upgraded with Real Time Kinematics (RTK) capabilities as this makes a considerable improvement to the quality of the work that they produce.

6.1.8 Spray equipment

Before spraying, it is useful to flush and residual air bubbles from the system and to check if any leaks can be identified from damaged connections, hoses, etc. Typically, this can be done on the ground by adding 1 to 2 liters of water to the tank and powering up the UAV and controller. If necessary, loosen the valves on the nozzles and spray the water out while the UAV is on the ground, checking for leaks and addressing them as appropriate. When the water has run out, the valves should be retightened. This procedure will flush any air bubbles from the system.

6.1.9 Calibrate sprayer

Good UAVs will be fitted with an automatic internal-pump calibration system. After removing the air bubbles and with an empty tank, the test water should be added according to the manufacturers instruction, the amount and nozzle types entered into the system and the UAV set to run the calibration system on the ground. This should be repeated for a second pump if it is present. Placing graduated measuring cups under the nozzles will allow the comparative outputs to be judged. Any irregularities could mean that nozzles are worn or damaged and need to be replaced. If this is not the case, then there is an imbalance in the system that may require further investigation according to manufacturer's recommendations.

This should be done before the first use and periodically throughout the season. Spray pattern is hard to calibrate without specialist equipment and so the focus should be on making sure that the appropriate nozzles are correctly inserted and undamaged.

6.1.10 Crop and pest targets

Before spraying, the identity of the crop, growth stage and canopy height should be confirmed along with the location of pests and diseases that might be suspected or previously identified by remote sensing. It is important to check that the nozzles and pressure settings and formulation are appropriate for delivering the right sized droplets for the job. Only pesticides appropriately registered for use against the target from UAV application should be used.

6.1.11 Monitoring environmental conditions

Records should be made of wind speed and direction, temperature, humidity and precipitation as well as the length of the spraying operations.

6.2 BMPs for mixing and loading

It is important to protect water sources from contamination when mixing and loading pesticides and when rinsing equipment and pesticide containers. Mixing and loading of pesticides should not occur within 120 m of any private or public drinking water supply or within 50 m of surface water. UAVs should be filled directly from any source waters unless a back siphon prevention device is present. Protect all resources from point pollution resulting from pesticide concentrates, mixtures, or wastes. Mix and load chemicals on a concrete pad or other impervious surface if possible. Avoid pesticide spills and prevent back-siphoning into wells or surface water impoundments.

6.2.1 Personal protective equipment (PPE)

Those handling pesticides should wear the appropriate PPE. For mixing, loading and decontamination of the UAV, this should include long sleeves and long trousers, boots, face protection, chemical resistant gloves, and

a chemical resistant apron. When flying the UAV, PPE is not required but it must be used when in contact with the UAV after use and when handling the pesticide concentrates.^{xxi}

6.2.2 Mixing sequence

UAV applicators should aim for mixes that require minimal agitation. The standard order in which tank mix partners are added to the tank is to use the acronym **W.A.L.E.S.** (Wetable powders, Agitate, Liquid flowables, Emulsifiable concentrates, Surfactants). 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. Modifications to this suggest that it could be **W.A.M.L.E.G.S.** with Microcaps added before liquid flowables and Glyphosate last before Surfactants.

If there are no recommendations from the manufacturers of the pesticides used, the mixing order should be tested in a jar. Always wear personal protective equipment (PPE) when performing a jar test. Do so in a safe and ventilated area, away from sources of ignition:

- Measure 500 ml of water into a one litre glass jar. This should be the same water you would fill a spray tank with.
- Add ingredients according to tested order, stirring after each addition.
- Let the solution stand in a ventilated area for 15 minutes and observe the results. If the mixture is giving off heat, these ingredients are not compatible. If gel or scum forms, or solids settle to the bottom (except for the wettable powders) then the mixture is likely not compatible.
- If no signs of physical incompatibility appear, test the mixture using a spray bottle on a small area where it is to be applied.

6.2.3 Spray water

Water is one of the main inputs into a spray operation and water is also critical to the performance of pesticides. There are four main water quality indicators related to pesticide performance:

- **Water hardness** is caused by positively charged minerals, primarily calcium and magnesium, but also sodium and iron. These cations can bind to some herbicides (glyphosate is the best-known example, also 2,4-D amine), reducing its performance.
- **Bicarbonate** can inhibit herbicide activity, and also make some herbicides more difficult to mix. The most commonly affected herbicides are members of the Group 1 modes of action, products like clethodim, sethoxydim, as well as MCPA amine and 2,4-D amine. Definite guidelines are hard to find because the antagonistic effect of the bicarbonate ion depends on the presence of other ions such as sodium and calcium.
- **pH** values between 4 and 7 are considered acceptable. But some herbicides, notably those in the Group 2 modes of action, have specific pH needs to dissolve properly. For example, the sulfonylureas and triazolopyrimidines) dissolve better at higher pH, whereas the imidazolinones tend to require lower pH. Label directions are important, sometimes calling for specific adjuvants. Some pesticides, particularly insecticides, can break down rapidly in higher pH water.
- **Cleanliness/turbidity.** Water may contain suspended solids such as clay. Some chemicals are sensitive to this, as they are readily adsorbed to soil particles, and so turbid water can reduce their effectiveness.

Water as a carrier can also affect the spray droplet. Under hot and dry conditions, water in the droplets can evaporate and produce smaller droplets that are more likely to drift (< 150 microns). Water-based droplets landing on waxy leaves can bounce off or shatter and even when they stick, the leaf-wax may prevent the entry of more water-soluble pesticides. In order to avoid these things adjuvants may be added to the mixture, Examples include surfactants, oils, compatibility agents, buffering and conditioning agents, de-foaming agents, deposition agents, drift control agents, and thickeners.

6.2.4 Surfactants

Also called wetting agents and spreaders, these are often incorporated into formulations or sometimes are added to the spray tank. They physically change the surface tension of a spray droplet. For a pesticide to perform its function properly on a plant, the spray droplet must be able to wet the foliage and spread out evenly. Surfactants make the area of pesticide coverage larger, which increases the pest or disease's exposure to the chemical. Surfactants are particularly useful when applying a pesticide to a plant with waxy or hairy leaves. Without proper wetting and spreading, spray droplets often run off or fail to provide good coverage to the surfaces. Too much surfactant, however, can cause excessive runoff, which may make the pesticide less effective. Surfactants are classified by the way they ionize, or split apart, into electronically charged molecules called ions. Use only the type as directed on the label. Using the wrong surfactant can reduce the effectiveness of a pesticide product and increase the risk of plant injury. Always follow the label recommendations.

Oil based formulations achieve slightly smaller droplets than water-based systems^{xxii}

6.3 BMPs during application

6.3.1 Application accuracy

It is important to make an accurate application to the crop to ensure that the materials applied reach the target area as efficiently as possible and that product is not wasted or drifting to off-target and environmentally sensitive areas. The rate should be as recommended to control the target pest, disease or weed and not increased so that unwanted effects on the crop or local environment become a risk. Rates increased above recommendations or outside the recommended application window can also lead to chemical residues which may exceed agreed maximum residue limits (MRLs) in trade of the produce. Inaccurate application means that the desired effects may be compromised, and the crop quality and value decreased. Always follow the label recommendations.

6.3.2 Environmental variables

Spray efficiency is greatly influenced by local meteorological conditions at crop height. Wind velocity and direction, temperature, relative humidity and the likelihood of rain all influence spray deposition. The distance a spray droplet travels depends on the droplet size and downward velocity, the release height and the ambient conditions. Vortices created by the UAV will also influence spray distribution efficiency and can also contribute to drift in some circumstances.

Aerial spraying is normally carried out when the surface wind speed is less than 6-7m/sec which is a safe speed for aircraft handling and safety. UAVs are considerably lighter than spray aircraft and may suffer problems at wind speeds in excess of 3 m/sec. Wind speed and direction will also influence flying height. When the wind speed is less than 3m/s, a boom height of between 2 and 3 m above the crop will ensure good lateral movement of the spray. Application at 1.5 m can be less efficient due to the turbulence created^{xxiii} but flying height must be reduced if the wind speed exceeds 3m/s. Applications of greater than 4 m above the crops seem to be less efficient.

Hot and dry conditions will increase the evaporation of water from the spray droplets, causing them to decrease in size. Droplets < 150 microns in diameter are more prone to drift than larger ones. In UAV applications, fog and mist can decrease visibility which is key to keeping the UAV in line of sight. Likewise, applications should only be made during the day. No licensing systems that we are aware of permit applications with UAVs at night because of this.

6.3.3 Droplet size and drift potential

Because a drone payload is relatively small, typically 5-25 L, application volumes will need to be low to increase the efficiency of the spraying application. For manned aircraft with a 750 to 2,250 L hopper, 18 to 36 L/ha are the lowest common-place application volumes achieved. The less water is used, the smaller the droplets that are needed to deliver the correct dose to the target can be, but if they are in the American Society of Agricultural and Biological Engineers (ASABE) category of Fine or Very Fine (< 150 microns in diameter) they are much more prone to drift. Drift control with coarser sprays requires higher volumes, and true droplet-size-based low-drift spraying producing ASABE medium droplets can't be achieved at volumes less than 45 to 65 L/ha which are impractical for UAVs.

ASABE developed a droplet size classification system that ranges from extremely fine to ultra-coarse based upon Volume Mean Diameter (VMD) measured in microns. As shown in Table 2.

Table 2: The American Society of Agricultural and Biological Engineers (ASABE) droplet size classification system

Color Codes for Droplet Size

Category	Symbol	Color Code	Approx. VMD Range (microns)
Extremely Fine	XF	Purple	<60
Very Fine	VF	Red	60-145
Fine	F	Orange	145-225
Medium	M	Yellow	226-325
Coarse	C	Blue	326-400
Very Coarse	VC	Green	401-500
Extremely Coarse	EC	White	501-650
Ultra Coarse	UC	Black	>650

At 18 L/ha, a larger UAV would be able to apply to 1 ha per load. While this is sufficient for spot spraying, or for treating small plots such as rice paddy, it is a constraint in larger fields. This creates an obvious advantage for Ultra Low Volume (ULV) technology in larger production units, with application rates of 5 to 10 L/ha. The only way this will provide sufficient coverage is with finer sprays, ASABE Fine to Very Fine, which are more likely to have problematic off-target movement and evaporation issues as well as wider distribution created by rotor blade vortices.

Low drift or air induction nozzles generate larger drop sizes from the same volume of applied material with less drift potential, but the drive for UAVs will be towards ULV applications. However, use of low drift nozzles is recommended. The potential for drift needs to be considered in any UAV flight plans and sufficient buffer zones respected for sensitive off-target habitats and areas.

Figure 1: Spray distribution affected by the vortices of a mini-helicopter UAV



6.3.4 Entry of people or animals into the spray area

If people or animals enter the spray area spraying should be stopped immediately until they have left or been removed

6.3.5 Loss of control

If control is lost the Return to Home setting should be operated. If the UAV does not return the flight of the drone should be followed (ideally with the use of a Drone tracker, which uses GPS or a cell signal). Verbal warning should be given to people in the vicinity. In the event of a crash, emergency procedures, as described in section 7 below should be followed.

6.4 BMPs after application

The purpose of this section is to provide best management practices (BMPs) after UAV applications. Stewardship recommendations should be provided for the following technical areas:

6.4.1 Use of PPE

Those handling pesticides or the UAV after use should wear the appropriate PPE which should include long sleeves and long trousers, boots, face protection, chemical resistant gloves, and a chemical-resistant apron. When flying the UAV, PPE is not required but it must be used when in contact with the UAV after use and when handling the pesticide concentrates and containers.^{xxiv}

6.4.2 Disposal of empty pesticide containers

As pesticide containers are emptied, while wearing PPE, fill the pesticide container ¼ full of clean water, replace cap and shake container for 30 seconds. Pour rinse water into the spray tank. Repeat the cleaning two

additional times, shaking the container in different directions. Carefully rinse the outside of the container and the cap, catching the rinsate in a bucket and return it to the spray tank. Dispose of the cap as regular household waste and dispose of or recycle containers according to local regulations. Apply the diluted rinse material to the treated area according to label directions.

6.4.3 Cleaning after use

The UAV should be loaded and operated so that all the spray solution is used up. When finished, the machinery should be cleaned: while using PPE, the UAV is to be sprayed with water to decontaminate it, with care taken that the wash-water does not enter drains or water courses or create point source contamination near wells, etc. Three separate washings should be conducted. The tank should be triple washed with clean water and the waste disposed of in the same manner as the outside wash water. The tank should then be partially filled and sprayed-out on the ground to clean out the pipes and the equipment left to dry.

6.4.4 Mechanical inspections

Once dry, the UAV should be inspected for damage to the rotors. The integrity of pipes, clips and nozzles should also be checked. Record any issues found.

6.4.5 Documentation

Before leaving the spray site, records should be completed of what was done (products and amounts used, crops, targets, location), the equipment used, the personnel involved and the time and date. Any records of meteorological conditions should be added along with any comments on the spray operation and the state of the equipment before and after use. Any maps concerning the treated areas, buffer zones, sensitive areas, etc. should be attached along with any flight plans. All the documentation and flight logbook should be returned to a secure storage place and kept for three years at least or according to local regulations.

6.4.6 UAV transport and storage

The UAV should be transported securely in a separate compartment from any passengers. When not in use, the UAV should be stored in a locked and secure place away from dwelling space for people or animals.

6.4.7 Battery charging

Most battery powered UAVs use lithium polymer (LiPo) batteries. These have the advantage of being very light and powerful with a high discharge rate, hence the limited service time of battery powered UAVs. They can go through about 150 – 250 charging cycles but are relatively expensive. They are sensitive to oxygen and can catch fire if punctured. There are many recharge packs that are available but they can also be expensive. Smart LiPo recharging packs taking up to 8 batteries at a time can help to keep the number of power packs needed available.

6.4.8 Gasoline

Mini helicopters that take 2-stroke or 4-stroke and hybrid UAVs should be accompanied by sufficient fuel for the job. Gasoline should be stored in fire-proof, sealed cans and transported securely.

6.4.9 Use of images taken

The rules concerning ownership of any images taken by UAVs can be complex. Generally, the photographer holds the rights but individuals in many countries have the right to privacy and should not be able to be

identified in person or in their vehicles in any publicly available or traded images. The local laws that apply should be understood.

7. Emergency plan

An emergency plan should be prepared. These steps are suggested as part of a plan:

7.1 Identify hazards

Be aware of the UAV manufacture's hazard warnings and those concerning the pesticides used. In advance of spraying, be aware of any possible catastrophic failures that could occur, what the UAV's response will be to that, e.g. loss of contact, bird-strike, structural failure, battery fire, etc.

7.2 Identify who or what might be exposed

The area to be treated should be inspected and potential human, environmental or structural exposures identified and recorded. This can include the spray crew, bystanders, houses, schools, hospitals, etc. and also any physical impediments, masts, electricity wires, etc.

7.3 Evaluate the risks and mitigations

Consider the risks created by the hazards and the people, environments or objects that might be exposed. How can these risks be mitigated? What actions need to be implemented and by whom?

7.4 Record

The hazards, potential exposures, and mitigations need to be recorded along with any observations or alterations noted on site.

7.5 Review

Set a regular date to review the records, noting any instances of accidents or near misses and any changes that are needed to the plan.

7.6 Emergency action

In case of spillage during filling or if a crash occurs the contaminated area should be sealed off and pesticide clean up procedures that are generally described in CropLife International's 'Guidelines for the Safe Warehousing of Crop Protection Products' followed. These also describe emergency procedures, for example in case of a fire. The operator should have a dry powder or foam extinguisher available. If emergency services are involved they should be informed of the pesticide being used. The above mentioned guidelines also describe procedures to follow in the event of human contamination with pesticides.

8. Outlook

UAV technology is growing rapidly and the capabilities and quality of the of the equipment continues to increase. The use of spray UAVs began in rice and vegetable fields in Japan with mini-helicopters in the 1990s and has now grown with the addition of 4, 6 and 8 rotor battery-powered UAVs. The technology is well-suited

to small plots and rice paddies where there are considerable advantages both in the speed of the operation and the decreased possibility of operator exposure. New opportunities have arisen in precision agriculture where UAVs can be directed to treat infected locations only, considerably reducing the amount of pesticide needed which can help to meet sustainability goals. Though it is expected that drift from UAV applications will be somewhere on the continuum between ground and aerial application, there needs to be some more work to be precise about the buffer zones required to protect bystanders and sensitive environmental areas, water courses, etc.

Current UAV models, though much cheaper than conventional mechanized ground and aerial spray equipment, are limited in the payload that they can carry and their flight-time. This means that current equipment is very advantageous in units < 50 ha but is uncompetitive with conventional equipment on larger units. One solution is to operate multiple UAVs in a swarm, though there are issues with the deployment of this technology for civilian use due to its potential for misuse. There are a number of experimental UAVs that carry much larger payloads which may be more competitive over larger acreages.

Overall, the potential decrease in operator exposure from backpack spraying and efficiency savings in treating small fields are enormous benefits. With future developments in technology that are foreseeable, UAVs have much potential to lower the costs and risks in agriculture, for operators and the environment and making a significant contribution to sustainability goals with benefits for people the environment and the profitability of agriculture.

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