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Report on the State of the Knowledge – Literature Review on Unmanned Aerial Spray Systems in Agriculture

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Report on the State of the Knowledge – Literature Review on Unmanned Aerial Spray Systems in Agriculture

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Foreword

In 2019, the OECD Working Party on Pesticides (WPP) established a Subgroup which was tasked with defining aspects of drone technology which will influence the risk characterisation in comparison with existing pesticide product evaluations (e.g. aerial application), to establish if there are any *additional* requirements needed / information gaps to fill and to recommend an approach to the WPP to address any related risks.

The Subgroup arranged an information call-in request for April 2020, but the response was disappointing (only nine responses) and with WPP agreement a second information call-in request took place in September 2020. The requests when added to the references from the Canadian Regulatory Authority literature search generated 57 responses ranging from regulatory studies, research papers, presentations and abstracts.

A consultant was employed in October 2020 (funded by the Australian Pesticides and Veterinary Medicines Authority, APVMA) to review the responses to the information request as well as several research papers identified by members of the Subgroup. Supported by a small project team from the Subgroup, the consultant graded and reviewed the quality of the information provided. The completed literature review (see Annex A) was made available to the Subgroup in March 2021.

This thematic review is entitled ***State of the Knowledge – Literature Review on Unmanned Aerial Spray Systems in Agriculture***. The review defines aspects of Unmanned Aerial Spray Systems (UASS) technology that influence the risk characteristics in comparison with existing pesticide product evaluations (for example, comparisons with application using fixed-wing aircraft, helicopters, airblast, boom and knapsack sprayers), seeking to establish if there are any additional requirements to address any related risk.

This report recognises that OECD member countries will have different interests and requirements relating to the use of UASS to apply pesticides because of the nature of the crops grown or other targeted applications (for example, non-agricultural uses) and the degree of regulatory infrastructure already available. The document does not prescribe the use of any particular UASS equipment or approach but identifies factors that determine how the risks from UASS application differ from more established, traditional methods. It outlines factors OECD member countries should consider when assessing UASS use, either within existing risks already assessed, or when seeking to develop new assessments and models.

The OECD would like to acknowledge the contribution by the Australian Pesticides and Veterinary Medicines Authority of the Literature Review document drafted by a consultant, which formed the background information of this report. The report was prepared under the framework of the OECD Drone/UAV Subgroup which reviewed and provided input to the report, led by the United Kingdom. The report is published under the responsibility of the OECD Chemicals and Biotechnology Committee.

This report has been produced with the financial assistance of the European Union. The views expressed herein can in no way be taken to reflect the official opinion of the European Union.

Executive Summary

This document recognises that OECD member countries will have different interests and requirements relating to the use of drone (Unmanned Aerial Vehicle (UAV) platforms, and the associated Unmanned Aerial Spray Systems (UASSs) in relation to the application of pesticides, because of the nature of the crops grown, the infrastructure already available and their jurisdictions' legal requirements. The document does not prescribe the use of any particular equipment or approach but identifies factors that determine how the risks from UASS application differ from more established, traditional methods of application, which OECD member countries should take into account when considering related risks from adopting such new technology for the application of pesticides.

The use of UASS for pesticide applications has the potential to provide benefits such as the reduction of applicator exposure in comparison to backpack spraying, better quality applications in difficult to access scenarios (e.g., sloped vineyards), and the enablement of precise zone or spot application linked with UASS/UAV-based whole field scouting. These could contribute to the more sustainable use of pesticides; however, these potential benefits cannot be realized without improving the available data on UASS applications.

The process used by regulators for assessing the hazards and risks associated with the proposed use of pesticides considers human toxicology; operator and bystander exposure; dietary exposures; environmental fate and behavior; ecotoxicology; physical and chemical properties; and efficacy. The data that are lacking with UASS technology for regulators assessing risk is primarily that related to exposure, efficacy, and drift.

While the information from the review is not substantial enough to enable the development of fully harmonized use policies and guidelines for regulators and product registrants, it does provide an overview of the current state of knowledge and practice and outlines how the risk associated with UASS applications could be viewed and addressed.

This review concludes that a combination of UASS design, working practices and products applied have the potential to create significantly different risks from those associated with more traditional and established methods of application. The nature and relative degree of risk alters depending on the factors described above. It may be possible to enable limited UASS application by permitting use within existing 'risk envelopes', but in order to facilitate more widescale adoption of this technology regulators are likely to have to develop new and possibly bespoke assessments.

The Drone / UAV Subgroup has created experience and an understanding of the available information. It also has identified areas of additional work needed to support the development of OECD WPP guidance for the regulatory risk assessment and decision processes for UASS application of pesticides. For instance, there is a clear and urgent need for a set of standard testing protocols to be agreed for the assessment of UASS; standards are needed for calibration and appropriate deployment, for efficacy testing, operator exposure scenarios and for spray drift assessment. These methods are necessary to ensure that data is of an appropriate quality for regulatory decision making.

The next step must be to carry out work aimed at filling the identified gaps to develop new UASS focused models for use in regulatory approval processes, and this will require greater engagement with those bodies and organisations which create and provide such data.

1. Introduction

The use of UASS for applying pesticides has the potential to provide benefits such as the reduction of operator exposure in comparison to knapsack spraying, safer applications in difficult to access scenarios (e.g., sloped vineyards), and the enablement of precise zone or spot application linked with UASS/Unmanned aerial vehicle -based whole field scouting. However, these potential benefits cannot be confirmed and so realised without improving the available data on UASS applications to ensure they can be adequately evaluated from a risk assessment and risk management perspective.

The process used by regulators for assessing the hazards and risks associated with the proposed use of pesticides considers human toxicology, operator and bystander exposure, dietary exposures, environmental fate and behaviour, ecotoxicology, physical and chemical properties, and efficacy. For existing authorised products, the data that are lacking for regulators to assess application via UASS technology are primarily those related to human and environmental exposure, spray drift and efficacy.

Some published papers reviewed by this Group lacked the level of detail or raw data necessary to allow them to be relied on quantitatively for regulatory purposes. Many were not designed to specifically meet regulatory requirements. Of the papers obtained for this review 35 were not considered relevant, 53 were classed as relevant. Of those considered relevant 20 were also fully reliable for regulatory purposes and a further 25 reliable with restrictions. The most common reason for discounting the study was due to the lack of appropriate methodology for trial conduct (there is currently no existing protocol or standard for assessing pesticide application from a UASS) or lacked sufficient replication of the experiment. The rest were not relevant or not possible to include in the review, for example due to unavailable data or translated text. While the information from the review is not substantial enough to enable the development of fully harmonized standard work practices and guidelines for regulators and product registrants, it does provide an overview of the current state of knowledge and practice and outlines how the risk associated with UASS applications could be viewed and addressed.

This review concludes that a combination of factors, UASS design, operational characteristics and application practices have the potential to create different risks from those associated with more traditional and established methods of application. The nature and relative degree of potential risk varies depending on the factors described above.

It is not yet possible, based on the quality of the available data, to determine whether the nature and degree of risk is substantially different to that resulting from existing forms of application. In the absence of information to determine this the authors of this review conclude, based on the evidence reviewed, that the potential for it to do so exists to sufficient extent to warrant regulatory authorities taking a cautious approach to currently authorising the application of pesticides by UASSs. Furthermore, based on the findings of this review it has been possible to identify information requirements and processes that would enable regulators and others to determine the risks associated with this novel form of application. Generation and development of these information and processes is necessary for regulators to be assured that proposed UASS operations fall within established risk envelopes / parameters; and / or can be approved for use in their own right.

2. Human Health Considerations

2.1. Literature Review Findings

2.1.1. Bystanders

The literature review identified studies with measurements of airborne spray drift downwind of the target area which could be of relevance when assessing bystander and resident exposure. In most studies airborne drift was sampled using monofilament lines positioned on frames at different heights from the ground and at various downwind distances. Drift measurements taken at 2 m from the treated area represented a worst case for bystanders. As with all other pesticide application methods, airborne drift further downwind depends on the height and volume of the spray plume exiting the target area, its droplet size distribution and the meteorological conditions.

The literature reviewer noted that when the airborne drift measurements from line samplers are expressed as a percentage of the applied amount the results will be artificially high because the numbers are not corrected for sampling rate: hence the reported collection of more than 100% of the applied dose in some cases. Therefore, the results reported in these studies should be used only as a comparative measure between treatments within a particular study and not used to compare different studies.

The literature review also identified studies measuring airborne drift using active samplers (rotary impactors). In one study active samplers were positioned 5, 10 and 20 m away from the target zone on towers at 1, 2, 3 and 4 m above ground level. The reported overall averaged airborne spray drift percentage for the three UASS models under investigation ranged from 2.5 to 25%. Active samplers are often used with ultra-low volume applications due to their high sampling rate and collection efficiency, but comparison to passive line samplers is difficult.

2.1.2. Operator Exposure

The literature review identified very little information on levels of operator exposure resulting from the use of UASS. Operators may be exposed through contact with the UASS if residues are transferred to the skin during work activities. Qualitative observations and numerical simulations show that the spray released from a UASS will have an upward component that could lead to residues of the active ingredient accumulating on the aircraft. There is also potential that the aircraft will fly back through spray that has yet to settle.

One study showed average external residues on a UASS were five times that compared to on an air-assisted sprayer, potentially reflecting the higher concentration of the pesticide solution used for the UASS. In another study minimal active substance was recovered on a UASS with highest residues on the spray boom and arms. As operators may lift the UASS by the arms, wearing proper personal protection equipment (PPE), as required on product labels, is important.

2.2. Conclusions

Although studies on operator and bystander exposure were limited in the review, some data in process of publication may be available in the future. A data gathering exercise for operational practices mixing and loading scenarios would help with understanding the potential exposure pathways and with developing or adapting exposure scenarios to be representative for work activities with UASS.

The reviewed literature had little information on levels of operator exposure although some measurements of residues on different parts of the UASS are potentially useful for predicting exposure from contact with surfaces that have residues.

To understand the risks to operators from being exposed to pesticides through UASS spraying, information is needed on the potential for exposure to the pesticide concentrate, spray solution and surface residues from tasks such as mixing, loading, maintaining, cleaning and transport. The potential for increased risk of sensitization or irritation due to using high in-use concentrations is another area to consider. It is not known if the physical distance from UASS in operation effectively mitigates operator exposure to potentially higher concentration sprays. Once typical operational practices have been identified (i.e. the individual tasks being performed by the UASS operator and ground crew, their frequency and duration), it may be possible to use established exposure models and approaches to predict levels of operator exposure resulting from the use of UASS.

For bystander and resident exposure, regulatory authorities need to understand if and how the pattern of airborne spray drift from UASS differs from conventional application methods (both ground-based and aerial). Another consideration affecting the bystander and resident risk assessment is the potential use of more concentrated spray solutions for UASS applications to maximize the work rate for a small tank capacity and limited flight time. Application volumes of 15 L/ha are typical for UASS in Asia from where much of the data available is derived, and the necessitated use of fine spray qualities increases the risk of airborne drift in comparison to larger droplet sizes. In other regions, such as North America and Australia, the trend is towards larger application volumes and use of low drift nozzles.

2.3. Recommendations

For estimating bystander exposure further work is required to identify the impact of turbulence on the levels of airborne drift and the variability of turbulence with the different UASS platforms (e.g. number of rotors and nozzle placement). Although modelling approaches are being developed to address this issue and to predict the influence of height and speed, this is not yet available for regulatory use. Future studies should use a single collector type and a single test protocol (following appropriate ISO standards or SETAC (Society of Environmental Toxicology and Chemistry) DRAW (Drift Risk Assessment Workshop) workshop proposals) to allow data pooling and comparison, and all aspects of the study (such as equipment calibration and replication) should meet regulatory standards. (Note – links to referenced workshops and Standards are in Annex C).

To understand the risks to operators from being exposed to pesticides through UASS spraying, information is needed on the potential for exposure to the pesticide concentrate, spray solution and surface residues from tasks such as mixing, loading, maintaining, cleaning and transport. The potential for increased risk of sensitization or irritation due to using high in-use concentrations is another area to consider. Once typical operational practices have been identified (i.e. the individual tasks being performed by the UASS operator and ground crew, their frequency and duration), it may be possible to use established exposure models and approaches to predict levels of operator exposure resulting from the use of UASS.

3. Environmental Considerations

3.1. Literature Review Findings

Data of most relevance to environmental exposure measured off-target spray drift, deposition to the target or impact of rotor downdraft. The literature review aimed to answer two key questions: how the amount and distance of drift resulting from spraying by UASS compared to other spray equipment and whether UASS presented any specific risks that needed to be considered. Some of the unique risks may be the release height of application; the nozzle position in relation to rotors; understanding the turbulent air flow from multi-rotors and potential interaction of any downdraft from rotors with canopy or ground as well as effect of UASS design, height, and forward speed on potential downdraft. While these aspects still need to be confirmed there are papers that did try to compare UASS to existing methods and based on that data these are some conclusions /recommendations.

3.1.1. Differences in UASS spray drift versus existing application methods

At least one study each directly compared spray from UASS to knapsack, ground boom/airblast sprayer or crewed aircraft. Two reliable studies contrasted drift from UASS against standard spray drift curves used by some regulators for ground sprayers. Compared to a drift curve for ground boom sprayer, the UASS with fine spray generated more drift, as might be expected due to greater release height (note that the use of drift reducing nozzles would need to be balanced against retaining efficacy). Compared to a drift curve for airblast sprayers, drift from UASS was lower for both coarse and fine droplets than airblast sprayers in vineyards, and less or comparable with fine spray. This may reflect that rotor downdraft creates a downward directed spray as opposed to ascending from airblast sprayer. We recommend contacting study authors to source additional data in a format that may be useful for inclusion in a spray drift database. There is enough data for the beginnings of an empirical database and standard drift curve, but additional data would ensure conclusions are representative.

3.1.2. Consensus needed on spray drift/deposition sample collector

The review discusses the merits and limitations of sampler material. Differences in samplers used, and whether they permitted residues to be expressed per surface area and therefore as percent applied, restricted direct comparison of different studies. It is proposed that regulators decide on a preferred sampling method and material to make future trial data more useful. This is not specific to UASS and existing ISO standards already describe a range of appropriate sampling materials, but it could be considered in the context of reviewing existing ISO standards, and the SETAC DRAW workshop, which also previously considered this, may also have useful information. One point specific to UASS was that the currently recommended sampler size (1000 cm^2) may be too large to ensure detectable concentrations from very low and ultra-low volumes.

3.1.3. Lack of calibration, flow rate checks and insufficient pump systems

It is important that the flow rate and amount applied are experimentally measured before every spray run and that this is reported to have taken place. Low-capacity pumps, often without pressure gauges, may not achieve the pressures required to keep nozzles open as application rate increases. Flow rate checks are critical to ensure nozzles are working properly. Total volume sprayed should be measured so deposition and drift can be reliably expressed as percent applied.

The development of UASS technology and design is rapid and improvements are already being observed with UASS on the market, for example, increased capacity pumps are fitted to UASS released to the market in 2021.

3.1.4. Application height affects drift and deposition

Ground boom sprayers usually operate at 0.5 m above the crop, while with crewed aircraft the boom is at least 3-4 m above crop. In the literature reviewed UASS most typically sprayed from 1.5-3 m above the crop. Investigation of the influence of release height on drift supported the hypothesis that spray drift increased with height.

Increased forward speed will reduce deposition unless flow rate is adjusted and may weaken the interaction between UASS downdraft and the canopy. Understanding how different operating practices affect drift may in future allow for an optimal application height and flight speed to be identified to reduce drift.

3.1.5. Nozzle position affects drift

It is accepted (ISO standard 16119-5, point 5.9.2) for crewed rotary aircraft that nozzles should be within 75% of the rotor diameter to reduce drift. At present not all UASS are configured in this way. Some studies concluded that greater drift occurred if nozzles were placed under rotors, beyond or close to the UASS rotor diameter (as illustrated in Figure 1), as opposed to within the rotor diameter. The same recommendation on positioning nozzles within 75% of the rotor diameter for UASS could decrease off-target losses. Where best to place nozzles and boom in relation to rotors requires further investigation, as some nozzles are placed directly under rotors, assuming downwash will minimise drift, but as downwash can be weakened by forward speed, this is not necessarily true.

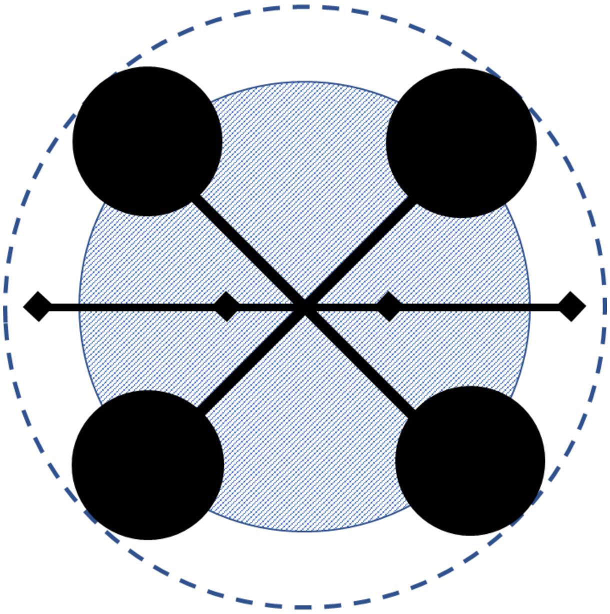

Figure 1: Schematic illustrating the spray nozzle location (denoted as diamonds on the horizontal line, representing the boom) relative to UASS rotors (denoted as the four black circles). The larger dotted line represents the circular area covered by the rotors. The shaded area within the larger circle represents the area covered by 75% of the rotor diameter.

3.1.6. Effect of UASS downdraft on canopy penetration and environmental exposure

Simulations and field measurements confirmed the velocity of downdraft from UASS rotors is fastest when at low altitude and low speed. Downdraft decreases with height and is weakened by increasing forward speed, turning to outwash if forward speed exceeds downdraft speed.

Downdraft may interact with the crop canopy or ground resulting in different spray deposition to other spray methods. It is not known if the force of downdraft affects the amount of pesticide intercepted by a crop and reaching the ground, or if subsequent passes dislodge any previously deposited spray from leaves. This has implications for assessing pesticide concentrations in soil and the exposure of non-target soil organisms. Conversely, turbulent airflow could cause a rebound effect where spray bounces back from the soil surface or increases leaf movement, allowing spray to better penetrate the canopy or reach underside of leaves. Results that compared canopy penetration and ground deposition for UASS with other sprayers were mixed for different crops and at times confounded with effect of forward speed.

3.1.7. Research only compares whole field treatments

Two areas not addressed by the review that need further information were spot spraying by UASS and spraying using swarms of UASS.

There is mounting interest in precision application and only spraying localised areas where a pest or disease is present in a crop, rather than treating the whole field. This offers benefits such as lower water use, reduced application of pesticide overall and lower off-target deposition. Though this interest is not specific to UASS application, such systems are potentially well suited to this; by combining remote sensing of weeds, pests or disease with variable rate, or spot spraying, the process could be automated and offer far greater work efficiency compared to knapsack sprayers. As with other spray methods for spot spraying, overall reduction in pesticide application across a whole field does not necessarily equate to lower risk to the non-target species if the organism comes into contact where the spray is applied (i.e. direct exposure or via consumption of residues on dietary item). This approach will decrease the amount of active substance applied compared to a whole field application. Regulators will need to determine how the environmental exposure arising from spot treatments compares to whole field treatment.

3.2. Conclusions

Conclusions from considering the environmental context of UASS application:

- Application height, speed and droplet size are the major factors affecting spray drift and deposition that should be considered by regulatory authorities;
- The position of nozzles relative to UASS rotors may have a significant effect on spray drift. However, at this time there is insufficient information available to assess the nature and degree of risk which can arise leading to the conclusion that it is not possible for regulatory authorities to assess the respective risks that arise from UASS with differing configurations (e.g. number and location of rotors, the power they generate and nozzle position relative to the rotors);
- There are some currently available data on drift from UASS that would be considered reliable from a regulatory standpoint to quantify UASS spray drift potential to support off-site exposure estimation in a risk assessment. These data could be gathered to develop a draft standard spray drift curve or a predictive model to estimate off-site movement that could inform regulatory exposure estimates. Authors of some other papers considered in the review could be contacted as to whether additional raw data on drift from UASS are available. Data from such studies can be accumulated to derive a statistically supported interim drift prediction curve;

- Downdraft from UASS has the potential to interact with the crop canopy or ground and result in different environmental risk compared to that arising from application using established technologies. At present, data are limited and suggest that lower soil exposure may arise from UASS application; this would mean that existing regulatory crop interception assumptions may be protective of UASS application. However, data are limited to two studies studying deposition in wheat crops also sprayed with knapsack or ground boom sprayers.
- More research is required to expand this information and to confirm these effects. Initial ideas are at Annex B.

3.3. Recommendations

- For UASS, flow rate must be checked, and the amount applied measured before every spray run. Studies should report whether this has been conducted;
- Encourage manufacturers to improve the spraying equipment on UASS, especially the pumping systems and controls, to meet the requirements on application rates and quality. Survey manufacturers about design developments and trends, with a view to regulators focusing research efforts on a commonly used standard UASS platform. In principle the spraying systems should comply with the requirements defined by ISO 23117-1 (which is under development);
- Drift data are available from the review that may allow a drift curve to be prepared for use by regulatory authorities. The data tentatively indicate that drift from UASS will be higher than ground sprayers, but lower than from crewed aerial application or airblast sprayers, but further data are needed for confirmation;
- To reduce the need for specific assessments for every UASS platform configuration, data could be gathered from this review and future studies into an empirical database classifying UASS models and operating parameters, and collating estimates of on-target deposition, spray drift, and in swath uniformity;
- Datasets be established enabling regulators to determine how spray drift from UASS application differs from that of established technologies. Ideally, datasets should be established to help develop a spray drift curve and a predictive model to estimate off-site movement for regulatory use; this would benefit from collaboration between regulators, academics, drone manufacturers and the pesticide industry;
- More research is conducted to determine how UASS downdraft impacts upon canopy penetration, interception and soil exposure in various crops and for different heights, speeds and number of rotors;
- Work should be undertaken to reach consensus on the type of sampler used for spray drift studies, as advised by the SETAC DRAW workshop. One option may be to incorporate this into any revision of ISO standards on drift trials. This is not specific to UASS but would be beneficial for cross-comparison between studies and in making broadest use of any data available;
- Consider operational practices, such as UASS accelerating or decelerating at the edge of field, or ‘sidestepping’ rows, while continuing to spray may result in unintended over application or increased off-target losses;
- Nozzles should, where practical, be positioned within 75% of the rotor diameter of UASS to reduce off-target drift. The influence of nozzle and boom position in relation to rotors on spray drift requires further investigation.

4. Efficacy Considerations

Literature Review Findings

The efficacy of products when applied via ground based hydraulic nozzle boom application equipment, airblast sprayers, knapsack sprayers and via crewed aerial spray systems is known. Efficacy data are typically generated by crop protection companies in support of product registration. Reliable comparisons of UASS efficacy with known systems would assist in understanding any differences in efficacy of these systems and whether specific consideration is required for pesticides which are to be applied via UASS. For example, the payload of a UASS may be less than that of a ground-based system with the spray solution applied at a much higher in-use concentration. An assessment should be made of how the concentration of the product influences effectiveness and crop safety. It is, of course, possible that some spray solution concentrations will be within those currently used in more conventional application systems.

As mentioned above, the review identifies the importance of accurate calibration of application equipment. Pump systems on UASS can sometimes be low capacity, low grade and lack a pressure gauge. The flow rate from the nozzles and the spray pattern and quality are affected by the pressure in the delivery system. Furthermore, different nozzles are designed to work at different pressures. The application rate is a combination of multiple factors: nozzle output, forward speed and spray height above the crop canopy influencing the spray swath eventually are all important in delivering the effective application rate. It is therefore important to be able to accurately control the system pressure to obtain the required spray pattern and quality. Accurate calibration of spray equipment must be conducted prior to application. The spray pattern will also determine the appropriate height above the crop to achieve the required coverage.

A good even coverage of spray is required to achieve optimum efficacy; and is essential for those active substances/ingredients with a contact mode of action, but potentially less so for those with a systemic mode of action. The review included trials investigating differences in application height and forward speed on coverage which has been examined in various studies.

In some cases though the experimental design meant one parameter confounded another making it difficult to draw conclusions on the impact of each. For example differences in forward speed were confounded with droplet size (finest spray tested with slowest speed and strongest downwash, larger droplets tested with fastest speed, which decreased penetration due to horizontal element to spray). Deposition results from one study with different working heights, were opposite to what would be expected. In this case the higher of two altitudes gave better penetration of the canopy, whereas one would expect reduced downwash interaction compared to lower application heights. However, but due to lack of replication this study was not considered fully reliable.

Some efficacy data are available from trials conducted in rice, wheat, sugar cane, cotton and orchards and have been discussed in the review summary.

Most of the data currently available is from the Asia Pacific region (the main area of current UASS use) and the spray droplet range used in these UASS experiments reported in the literature appears to be “fine.” Europe/ USA tend towards low drift technology and therefore more medium to coarse spray droplets. As this potentially affects coverage, there is a need for more information on droplet deposition and efficacy when UASS is used with medium or course spray droplet range. Therefore, the droplet deposition data discussed in the review may be of limited use with regards to extrapolation for efficacy. However, spray droplet spectrum will be determined by the nozzle type and pressure and does not depend on application platform.

Some of the studies have made comparisons between UASS and knapsack sprayers which have a motorised pump to achieve the operating pressure and may not be in common usage in many OECD countries. A knapsack with a motorised pump may give different coverage/deposition to one without a motorised pump. Therefore, trials where UASS was compared to motorised pump knapsack may not be representative to extrapolate conclusions to knapsack without this.

Conclusions

There is an extremely limited understanding of how the efficacy of pesticides applied from UASS differs from that of other forms of application equipment. There are currently insufficient published data to allow regulatory authorities to bridge existing efficacy for conventional spray application systems with UASS.

The studies summarised in the review cover a range of types of UASS, actives and crops. Application by UASS has been conducted using different release heights, forward travelling speed, active substances and nozzles. Little information has been given on calibration and the actual methodology. These are singular studies conducted disparately with no standard protocol.

The available efficacy data fall into the following categories, a comparison of spray methods or UASS alone; measuring effectiveness of biological control and / or measuring deposition data.

More emphasis has been made on deposition data in these studies as opposed to comparisons in biological effectiveness. Since not all OECD country regulatory systems consider deposition data when evaluating biological effectiveness and crop safety, it is unclear how applicable this literature is to the current regulatory approach.

All the UASS treatments have been at a higher concentration when a comparison with a ground-based applicator can be made. Higher concentrations of active ingredients / substances in a spray solution can cause detrimental crop safety effects such as phytotoxicity. None of the trials reviewed in the present review have considered or reported any aspect of crop safety.

Based on the limited evidence available, applications made by UASS tend towards delivering a lower degree of efficacy than ground-based boom or knapsack sprayers. However, this is not universal and it is not possible to quantify the relative performance of the technologies. UASS applied product efficacy may be improved using adjuvants. Although some studies showed that performance can be comparable with a ground-based application, these have been with systemic active substances where coverage is not as important as it is with active substances with a contact mode of action and it cannot be concluded that systemic actives are the exception to this rule.

If comparability of efficacy performance from treatment with different application regimes and under what conditions can be consistently demonstrated, then this may permit extrapolation from one spray method to another. Alternatively, data could be generated to demonstrate the efficacy of a product when applied from a UASS tested alone.

A data base of classifications of platforms and configurations is proposed and some data from these studies were considered useful for that. Information over time may allow us to group these for the purpose of assessment.

Recommendations

We recommend that structured programmes of work are established to develop datasets enabling regulators to determine product efficacy (where this is considered as part of registration processes). The work should be directed to generate packages of studies/datasets developed using standard protocols containing information on: configuration of the equipment (number of rotors, nozzle type and position relative to the rotor, etc), flight patterns (height and speed); spray solution (volume of product, use of adjuvants, impact on crop safety etc); deposition; comparability of treatment regimes and degree of control.

5. Conclusions and Recommendations

Conclusions

This report concludes that a combination of UASS design and working practices (including those arising from different crop types) have the potential to create different risks from those associated with established methods of application. Currently there are inadequate, reliable data available to satisfy all the requirements of many regulatory authorities. Good practice in methodology and study design is vital. The differences in risks from other spray methods are due to height of application above canopy, turbulent airflow/downdraft due to rotors, UASS specific operating activities/tasks, nozzle position, size of droplets and coverage. The nature and relative degree of risk alters depending on the factors above. It may be possible to enable UASS application by permitting use within existing risk envelopes, (Report on application to Vines - (Anken & Dubois)) but to facilitate more widescale adoption of this technology regulators are likely to have to develop UASS specific assessments.

Actions are required to improve the reliability of data and application of pesticides via UASS in practice. This can be done by ensuring the existing standards are updated to include important aspects for UASS. The importance of calibration of the spray system cannot be over emphasized. UASS manufacturers should be encouraged to improve the pumping systems placed on UASS. Additionally, a user-friendly summary of best practice, pitfalls, troubleshooting guide (both for generating trials data and applying pesticides via UASS in practice) should be developed and published.

Some data on drift from UASS currently available is considered reliable and can be used to start to develop an interim standard drift curve to inform regulatory estimates in comparison to known drift curves for ground spray equipment. Additional drift data for UASS may be obtainable from authors of other papers in the review. These data could also be added to a database for future regulatory reference and used to increase confidence in the interim drift curve. Further work is required to characterize the spray distribution more accurately from UASS, alongside operational practices that could be important to operator exposure and off-target losses.

The project has indicated that the configuration of the UASS does have an influence on pesticide spray drift and consequently on human health and environmental exposure. The number and power of the rotors; the type and location (relative to the rotors) of the nozzles used; a combination of the height at which the drone flies above the crop/area to be treated and speed at which it flies will influence the amount of spray drift, downdraft and interception of spray by the crop canopy.

The project has also indicated that there is a lack of information on work practices. Standard work protocols would assist regulators in constructing exposure scenarios to help understand the potential degree of worker exposure. The protocols should cover practices such as frequency and duration of handling and filling operations (including whether closed transfer systems are used), length of a working day, proximity to spray operations and cleaning operations. Information on cleaning operations could be supplemented by data/information indicating exposures from residues to be cleaned from the machinery following spray operations. In the absence of any information on these points, we recommend that regulatory authorities adopt a ‘reasonable worst-case scenario’ approach to assessing exposures. Regulatory authorities should also take steps to ensure that UASS operators intending to spray pesticides are suitably qualified and have a good understanding of best practices in pesticide application. For the operator exposure component, there is also the need to construct exposure scenarios that are representative of the mixing loading steps and the work activities for UASS.

There is a clear and urgent need for a set of standard testing protocols to be agreed upon for the assessment of UASS. Standards are needed for calibration and appropriate deployment, for efficacy testing and for spray drift assessment. These methods are necessary to ensure that data are of an appropriate quality, are considered acceptable across jurisdictions for regulatory decision making and can be combined to build up data sets. Protocols and standards for the conventional (non UASS) spray application of pesticides are available. Some aspects such as calibrating spray equipment and sampling are generic to all spray equipment in principle. As spraying by UASS is an area where services may be offered by companies that are primarily UASS specialists or pilots and not necessarily always experts in pesticide application, the review recommends that best practice and potential pitfalls should be emphasised. Some operational practices will also be specific to UASS.

Another aspect that needs additional consideration for UASS applications that is relevant for dietary exposure (e.g., crop residue) and operator exposure is the potential reduced carrier volume - which may influence spray concentrations, compared to conventional ground applications. However, for dietary exposure, it should be noted that piloted aerial applications (e.g., rotary or fixed wing aircraft in North America and Australia) and remotely operated helicopters (e.g. radio controlled helicopters in Japan) have utilized lower carrier volumes for several decades. Experience with these conventional application systems has led some OECD countries to stop requesting field crop residue studies for these application methods. For the operator exposure component, there is also the need to construct exposure scenarios that are representative of the mixing and loading steps, handling of the UASS and the work activities for UASS.

Recommendations

Through its work under the initial charge from the WPP, the Drone / UAV Subgroup has created experience and an understanding of the available information. It also has identified areas of additional work needed to support the development of OECD WPP guidance for the regulatory risk assessment and decision processes for UASS application of pesticides.

With respect to data generation, the focus on generating information / data for submission to regulatory authorities should inform estimates for off-site movement, determine potential operator/handler exposure, and assess crop residue contribution to human dietary exposure in risk assessment and regulatory approval processes. Generated data will also contribute toward the evaluation of existing regulatory models or the development of new UASS-focused models that estimate exposures in risk assessment and regulatory approval processes.

Below are some specific recommendations for considerations in developing new assessments and models.

1. Establish database to classify UASS into groups to reduce burden of testing each different platform/configuration.
2. Survey manufacturers about future trend of UASS design/ use profiles to produce a standard platform as a common starting point for regulators (others may differ and need bespoke assessment but would cover most common uses).
3. Encourage manufacturers to develop improved spray systems including the pump systems, nozzle placement and closed transfer loading systems.
4. Develop set of standard methodologies that will support regulatory decision making.
5. Develop and publish a user-friendly summary of best practice (including the essential nature of calibration), pitfalls and a trouble shooting guide (both for generating trials data and applying pesticides in practice), including preliminary

recommendations for operational parameters (release height, application volumes, forward speed and spray quality).

6. Promote the advice in Annex D recommendations for researchers conducting UASS drift studies.
7. Develop an empirical database and standard drift curve or model to estimate off target exposure.
8. A data gathering exercise for operational practices mixing, loading, cleaning and transport scenarios.
9. Develop a useable publicly available model for predicting spray deposition and drift including parameters for static hovering, forward speed and spray equipment.

Annex A. Full Report

State of the Knowledge Literature Review on Unmanned Aerial Spray Systems in Agriculture

OECD Working Party on Pesticides (WPP), OECD Drone Sub-Group

Bonds Consulting Group LLC, Australian Pesticides and Veterinary Medicines Authority

June 2021

This document is available as a separate annex under reference ENV/CBC/MONO(2021)39/ANN1.

Annex B. Further research ideas

The following ideas are borne out of knowledge gaps identified by the review of the current science and by regulators considering the potential for UASS use.

1. Investigate the in-flight uniformity of spray deposition both on- and off-target. It may be worth considering the influence of reduced weight as a spray pass goes on, and the consistency of flight height and speed during a spray pass.
2. Investigate the influence of spray nozzle positioning relative to the rotors on UASS and the effect on spray drift to identify optimal positioning that minimises drift.
3. Investigate the influence of different application practices, for example at the start and end of a pass to determine the best practice to minimise off target losses and subsequent human and environmental exposure.
4. Investigate the impact of rotor downdraft on how much spray penetrates the crop canopy to the soil surface. This could be studied both in the context of efficacy and environmental exposure.
5. Compare the efficacy of UASS applications to ground boom sprayers, airblast and crewed aerial sprayers.
6. Compare the spray drift (in both human and environmental exposure contexts) arising from UASS applications to ground boom sprayers, crewed aerial sprayers and airblast sprayers. Comparisons could also be made to standard spray drift curves used in pesticide regulation (for example, the Rautmann and the Van de Zande drift curves used by European regulators, the Wolf and Caldwell and the Ganzelmeier drift curves used by Canadian regulators, the AgDRIFT model drift curves used by USA and Australian regulators).

Annex C. Further information on referenced workshops and International Organisation Standards

Information on SETAC DRAW workshop:
Link to website giving the context and scope of the SETAC DRAW workshop: https://www.spraydriftmitigation.info/setac-draw-workshop
SETAC DRAW Workshop reports:
Workshop I summary report (February 2016): https://cdn.ymaws.com/www.setac.org/resource/resmgr/Workshops/DRAW_Summary_Report.pdf Workshop II summary report (February 2017): https://cdn.ymaws.com/www.setac.org/resource/resmgr/draw_summary_report_phase_ii.pdf
Relevant ISO standards:
ISO 22369-2: Crop protection equipment -- Drift classification of spraying equipment -- Part 2: Classification of field crop sprayers by field measurements
ISO 22866: Equipment for crop protection -- Methods for field measurement of spray drift
ISO 22856: Equipment for Crop Protection – Laboratory drift methods measurements
ISO 23117-1 – under development - Agricultural and forestry machinery — Unmanned aerial spraying systems

Annex D. Study conduct recommendations for researchers conducting UASS drift studies

The following recommendations are for researchers investigating environmental exposure arising from application of PPP (Plant Protection Products) using UASS. In the absence of a formal experimental protocol for UASS studies, these recommendations will enable researchers to conduct robust experiments that could be of use to regulators.

- Calibrate and test the spray quality of each UASS set up. Each individual nozzle should be tested so that the spray volume released over a period is quantified. The amount remaining in the spray tank at the end of spraying should also be measured. This should be done for every experimental run.
- Conduct experiments with true replication, with at least three spray passes for each treatment to enable calculation of variance and other statistical analyses.
- Record meteorological conditions on site at the time of the experiment so that these can be included as covariates in statistical analyses and add context to findings. We recommend measuring wind speed and direction (including the height at which these measurements are taken), temperature and humidity, and other variables as referenced in several ISO standards relating to spray drift data generation.
- Record the crop height and growth stage with reference to the BBCH scale (or similar) for the crop.
- Study the in-flight uniformity of UASS movement and spray deposition as acceleration and deceleration may confound experimental results.
- Conduct experiments with a minimum flight path of 20 metres for the UASS. This will enable researchers to have a sufficiently sized flight path for sampling at a consistent flight speed without acceleration and deceleration influencing spray deposition.
- Collect spray drift samples up to at least 50 m downwind of the UASS flight path and preferably beyond 100 m, with a high resolution of samples in at least the first 20 m. An increased sample number is encouraged.
- Clearly report the application height and ensure this is reported as height above the crop (or above ground if measuring a bare ground application) and how altitude is maintained (e.g., manual vs RTK (Real Time Kinematics) GPS (Global Positioning Satellites) or other autonomous UASS).
- Design studies to ensure that different application factors that may interact will not confound the results and with care that the effect of each factor on the results can be observed.

Annex E. Abbreviations

AgDRIFT	Agricultural DISpersal – a model for estimating near-field spray drift from aerial applications
APVMA	Australian Pesticides and Veterinary Medicines Authority
BBCH	Biologische Bundesantalt Bundessortenamt and Chemical Industry (Scale of key stages of phenological development in plants)
BCPC	British Crop Production Council (Congress invariably held in Brighton)
ISO	International Organization for Standardization
OECD	Organisation for Economic Co-operation and Development
PPP	Plant protection product
Risk envelope	Term used to describe a known set of parameters and effects based on a previous evaluation
SETAC DRAW	Society of Environmental Toxicology and Chemistry Drift Risk Assessment Workshop
UAAS	Unoccupied Agricultural Aircraft System
UASS	Unmanned aerial spray system
UAV	Unmanned Aerial Vehicle
WPP	Working Party on Pesticides