Turvallisuus- ja kemikaalivirasto

The use of drones in plant protection

Maa- ja metsätalousministeriö

Luke
LUONNONVARAKESKUS

Report by the Finnish Safety and Chemicals Agency (Tukes): The use of drones in plant protection

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The project on the use of drone sprayers in plant protection was funded by the Ministry of Agriculture and Forestry

Contents

1. Introduction

Major changes are taking place in the use of plant protection products. The European Green Deal[1] and the related strategies set guidelines for mitigating the risks from the use of plant protection products and for reducing the use of such products. The goal of the Farm to Fork and the Biodiversity strategies is to reduce the risks and use of plant protection products by 50% by 2030 and to reduce the use of the most harmful products by 50%. Reducing the risks and use of plant protection products calls for new and innovative pest monitoring and control methods, as well as an increasingly meticulous and precise use of chemical plant protection products. The opportunities provided by the use of unmanned aerial vehicles, or drones, for targeted pest control have attracted attention in Finland and more widely in the European Union.

Unmanned aerial vehicles and related technology are developing rapidly. Various types of drone sprayers are available, and they have been used especially in rice fields in Japan since the 1980s and in China since the early 2000s[2]. Studies are being conducted on, for example, the use of remote sensing methods to identify weed and pest damage. Drones could be used for the targeted spraying of weeds and pests thus identified. This kind of treatment could be safer and more effective for the user and the environment compared with using knapsack sprayers for patch treatment or a tractor for treating the entire area. The use of drones to spray plant protection products may involve risks not found in earlier techniques. A case-by-case risk assessment must therefore be carried be out.

The project focusing on the use of drone sprayers in plant protection was set up following the customer inquiries received by Tukes. Preliminary surveys of drone sprayers and their use were carried out back in 2016. Some of the proposed purposes for drone sprayers include targeted identification and control, the protection of sapling stands from elk damage, plant protection on golf course greens, challenging or hazardous operating environments, specialised crops and new areas of use. Discussions on drone sprayers have often led to the conclusion that, owing to the challenging technology and complex permit process, drone spraying would most likely be a service offered by contractors.

The Act on Plant Protection Products (1563/2011) currently does not allow the use of drones for the aerial spraying of plant protection products. It would be important to ensure that legislation keeps up to date on the development of new spraying techniques and enables the testing and adoption of innovative operating methods. **As a conclusion of the survey, we believe that the Act on Plant Protection Products should be amended to include an exemption concerning aerial spraying to allow the use of unmanned aerial vehicles, or drones, for spraying plant protection products.**

The proposed amendment does not restrict the purposes of drone spraying. A risk assessment must always be conducted for each individual case and the intended purpose. Drone spraying can only be approved if no other alternative exists or if the impacts on people's health and the environment are smaller than those of

[1] Europa.eu 2019: The European Green Deal. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.
[2] He, X.K. & Bonds, J., Herbst, A. & Langenakens, J. (2017). Recent development of unmanned aerial vehicle for plant protection in East Asia. International Journal of Agricultural and Biological Engineering. 10. 18–30. https://www.researchgate.net/publication/317779797_Recent_development_of_unmanned_aerial_vehicle_for_plant_protection_in_East_Asia.

spraying performed on the ground. In practice, as no risk assessment methods and criteria yet exist for this spraying method, drone spraying can only be approved for trial use, taking into account health security and environmental safety. As the risk assessment methods and approval criteria continue to develop, drone spraying can, according to the proposal, be assessed and approved for other uses, as well.

The following requirements and permits are essential for drone spraying: the suitability of the drone sprayer for the intended purpose, the substance's approval for drone spraying, registrations and permits related to aviation, and an exemption concerning aerial spraying (Figure 1). A more detailed description of the different areas of the permit process is provided in chapter

2.2. Process description

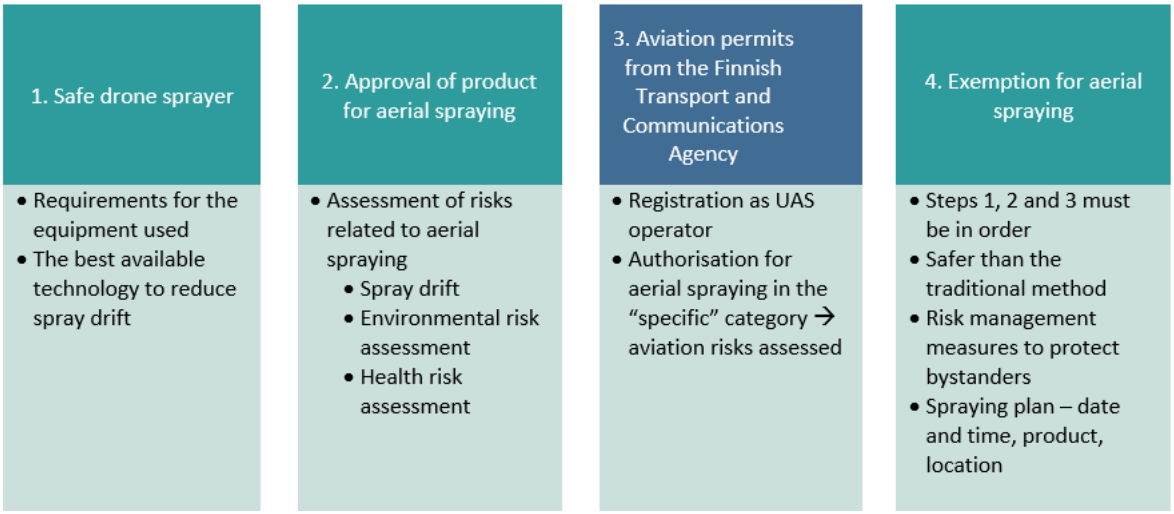

Figure 1. The requirements and permit processes related to drone spraying.

In this report, **drone** means an unmanned aerial vehicle (UAV) or remotely piloted aircraft system (RPAS), and **drone sprayer** means an unmanned aerial spraying system (UASS) suitable for use with plant protection products. This report deals with the use of drone sprayers to spray plant protection products. It does not discuss aerial spraying from a manned aerial vehicle or the spraying of biocides using a drone sprayer. Moreover, the report does not deal with the aerial spraying of biological control agents or fertilisers, as there is no legal obstacle for this.

The project on the use of drone sprayers in plant protection was funded by the Ministry of Agriculture and Forestry. Research scientists Ari Ronkainen and Pasi Suomi from Natural Resources Institute Finland, as well as Head of Unit Pauliina Laitinen and Senior Officers Emilia Laitala and Jouni Rokkanen from the Finnish Safety and Chemicals Agency served as experts in the project. This report compiles information obtained from expert interviews and from discussions conducted at the project workshop. A warm thanks to everyone who contributed to preparing this report!

2. Proposed amendment to legislation

2.1. Proposed amendment

Based on the investigation carried out in the project, we propose that the Act on Plant Protection Products should be amended to include an exemption allowing the use of drone sprayers for the aerial spraying of

plant protection products. In addition to the aspects included in current provisions, the following questions must be addressed in connection with the proposed exemption.

- The appointment of the competent authority and the supervision of and sanctions related to drone spraying.
- The exemption applies to the aerial spraying of plant protection products using an unmanned aerial vehicle (section 20 a, as proposed below) and includes a plan for aerial spraying, as well as a notification procedure for requests concerning the implementation of drone spraying. It is not currently possible to conduct a comprehensive risk assessment on the health and environmental impacts of drone spraying. Therefore, the use of drones for applying plant protection products can only be approved for trial use.
- Detailed provisions on the use of unmanned aerial vehicles for aerial spraying, including the requirements and restrictions concerning the drone sprayer, will be issued by a decree of the Ministry of Agriculture and Forestry.
- The approval of the plant protection product for aerial spraying. Assessments must be carried out on the risks related to the drone spraying of the substance and on drone spraying operations.

The Finnish Safety and Chemicals Agency proposes that sections 20, 21 and 22 of the Act on Plant Protection Products be reviewed and that the following words and phrases in bold be added to them. Comments concerning these additions are included as bullet points below.

Section 20 Aerial spraying of plant protection products

The aerial spraying of plant protection products is prohibited.

Notwithstanding the provisions of subsection 1:

1) The Finnish Food Authority can decide on the use of aerial spraying for controlling plant pests when deciding on the measures to be adopted to control or prevent the spread of plant pests, as laid down in the Act on the Protection of Plant Health (702/2003), if the pest poses an immediate hazard to plant health and there is no other reasonable and effective alternative for controlling or preventing the spread of the pest;

2) The Ministry of Agriculture and Forestry can decide, on a presentation of the Finnish Forest Centre's regional unit, on the aerial spraying of a plant protection product to control extensive forest damage to trees growing in the forest when deciding on the measures to be adopted to prevent the occurrence or spread of extensive forest damage, as laid down in the Forest Damages Prevention Act (1087/2013), if there is no other reasonable and effective alternative for preventing forest damage.

The decision on aerial spraying shall include details concerning the area of aerial spraying, the control measures and the date and time of their implementation, as well as the plant protection product to be used.

Section 20 a Aerial spraying of plant protection products from an unmanned aerial vehicle

- ***Because of the wide scope of this topic, it may be necessary to treat unmanned aviation under a separate section 20 a.***

1 subsection
Notwithstanding the provisions of section 20, subsection 1, the Finnish Safety and Chemicals Agency can decide, upon application, on the aerial spraying of a plant protection product from an unmanned aerial vehicle if no viable alternatives exist, or if the spraying advances

research and development focusing on site-specific crop management, or if the applicant can demonstrate that the impacts of aerial spraying from an unmanned aerial vehicle on human health and the environment are smaller than those of spraying on the ground, as specified in section 21, subsection 1, paragraph 1.

2 subsection

The applicant submits its aerial spraying plan for approval to the Finnish Safety and Chemicals Agency and appends to it proof of the requirements of subsection 1 and section 21 being satisfied. The application for aerial spraying complying with the aerial spraying plan shall be presented well in advance to the Finnish Safety and Chemicals Agency. The application shall specify the provisional date and time of spraying, as well as the volumes and types of the plant protection products to be used. The decision on aerial spraying shall include details concerning the area of aerial spraying, the control measures and the date and time of their implementation, as well as the plant protection product to be used.

3 subsection

The Finnish Safety and Chemicals Agency approves the aerial spraying plan upon application and can, based on a notification procedure, deem as approved applications for aerial spraying to be carried out according to an approved aerial spraying plan which do not contain significant changes and cannot be processed within the period specified by the competent authority.

- *We propose that deadlines be considered and determined by decree for the submission of applications concerning aerial spraying plans and aerial spraying operations, as well as for the approval of applications. One of the options discussed was to add the phrase "no later than 2 weeks before the planned aerial spraying" in the application for aerial spraying, but in practice, two weeks may be too long a time to wait for the authority's approval.*
- *The act or decree should specify the requirements (boundary conditions) for the notification procedure and enable operations to be launched after a specific period (e.g. two weeks), if the Finnish Safety and Chemicals Agency has not issued its response. If the application for aerial spraying deviates considerably from the aerial spraying plan, the Finnish Safety and Chemicals Agency must assess the ensuing risks and decide the matter, after a hearing, if required.*
- *Chapter 10 a of the Environmental Protection Act provides useful examples in this respect. A procedure such as that specified in section 115 b of the Environmental Protection Act should be considered for the notification procedure: If the application is incomplete, it can be supplemented once within the deadline set by the competent authority. If the notification has not been supplemented within the deadline, or if it remains incomplete after being supplemented, the notification will be dismissed, and the operations must not be initiated.*

4 subsection

The Finnish Safety and Chemicals Agency shall keep a record of the applications and permits referred to in subsections 2 and 3 and make generally available the important details in them, including the area to be sprayed, the planned date and time of spraying, as well as the type of the plant protection product to be applied.

- *This obligation to keep a record of applications and permits applies to all permits granted for aerial spraying. Therefore, it merits being expressed more emphatically, perhaps in a section of its own. The Ministry of Agriculture and Forestry and the Finnish Safety and Chemicals Agency would keep a record of the permits they grant.*

5 subsection

Provisions on the requirements for unmanned aerial vehicles used for the aerial spraying of plant protection products, as well as the details, practices, restrictions and schedules concerning the aerial spraying plan and aerial spraying operations will be issued by a decree of the Ministry of Agriculture and Forestry.

Section 21 Prerequisites for the aerial spraying of plant protection products

In addition to the other provisions of section 20, subsection 2 and ***section 20 a, subsection 2****, the following conditions must be met for the aerial spraying of plant protection products to be allowed:*

1) The impacts on human health and the environment must be smaller than those of a land-based application of the plant protection product;

2) The plant protection product to be used has been approved for aerial spraying;

3) The operator carrying out aerial spraying holds a certificate as referred to in section 10;

4) Aerial spraying will be carried out with equipment tested in accordance with section 12, subsection 2.

5) Under the framework directive, the enterprise responsible for providing aerial spray applications shall be certified by a competent authority for authorising equipment and aircraft for aerial application of pesticides.

- ***This comes directly from the framework directive. Further discussion is required to determine whether reference should be made to provisions on aerial spraying issued elsewhere in legislation. For example, the operator of an unmanned aerial vehicle (drone) used for spraying plant protection products must be registered as a UAS operator in Traficom's register, and if required, a risk assessment must be carried out for the operations as specified in aviation regulations.***

Section 22 Performance of aerial spraying of plant protection products

The aerial spraying of plant protection products shall be carried out with special care, ensuring that it does not cause a health hazard to humans or animals nor unreasonable damage to the environment. Notification of aerial spraying as provided in ***section 20, subsection 2*** *must be made well in advance to the Centre for Economic Development, Transport and the Environment, the municipal environmental protection authority and health protection authority, as well as the municipal veterinarian.* ***Notification of aerial spraying from an unmanned aerial vehicle as provided in section 20 a, subsection 1 must be made well in advance to the Centre for Economic Development, Transport and the Environment.*** *Aerial spraying is carried out under the supervision of the Centre for Economic Development, Transport and the Environment.*

- ***The following amendment concerning supervision is proposed for further discussion: "The Centre for Economic Development, Transport and the Environment is responsible for the supervision of aerial spraying."***

Detailed provisions on the procedure to be followed in aerial spraying, as well as the notifications ***and schedules*** *concerning spraying, will be issued by a decree of the Ministry of Agriculture and Forestry.*

2.2. Process description

The approval process for drone spraying comprises three parts.

1. **Permit for the drone spraying of a plant protection product.** An assessment must be carried out of the risks related to the aerial spraying of the plant protection product to be used, and the product and planned purpose must have been approved for aerial spraying.
2. **Aviation permits.** Drone spraying requires the operator to register in Traficom's UAS register and obtain an operational authorisation in the "specific" category. Aviation-related risks are assessed in accordance with the requirements of the "specific" category.
3. **Exemption for the aerial spraying of a plant protection product** with a drone sprayer.

The application submitted to the authority will be reviewed at the different stages of the permit process, and the applicant may be requested to supply further information and details required for processing. Before the permit decision is made, a hearing will be organised as specified in section 34 of the Administrative Procedure Act (2003/434) if the decision differs from the application. A decision on the application will be made after the hearing. The applicant can supply further information at the hearing.

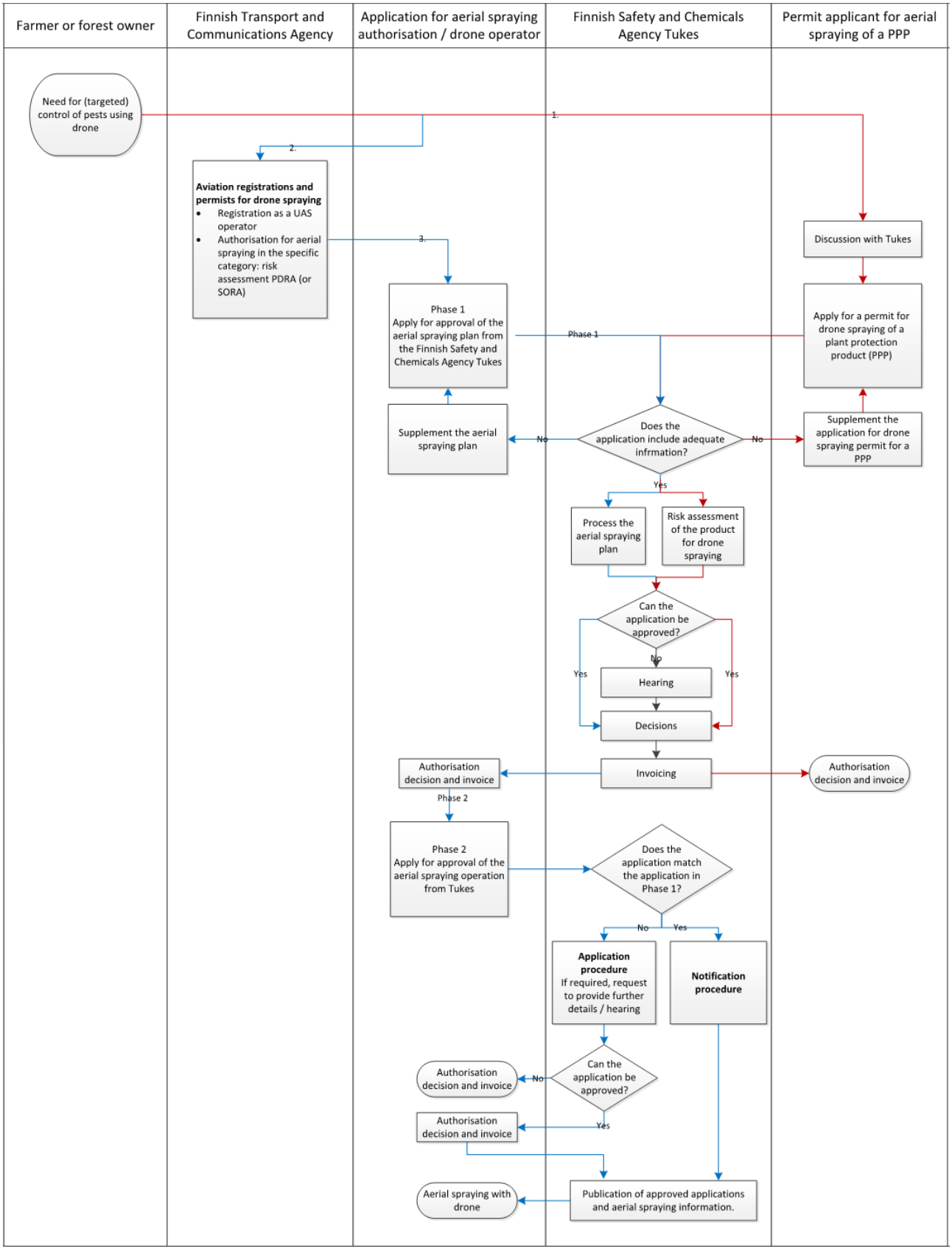

Figure 2. Description of the whole permit process related to drone spraying.

The permit process for drone spraying begins with an identified need for drone spraying. For example, a farmer or forest owner may have a need for targeted pest control using a drone. One of the prerequisites for drone spraying is that spraying is carried out with a reliable drone sprayer. Chapter 6 contains a detailed discussion of the requirements for drone sprayers.

1. *Permit for the drone spraying of a plant protection product*

A permit for the drone spraying of a plant protection product may be sought for trial use. Alternatively, the application may concern an approved product and a revision to its instructions of use to include drone spraying as one of the possible uses. In the case of a permit for trial use, the applicant may be, for example, a research institute, a testing facility, the party with marketing authorisation for the plant protection product, a drone operator or an advisory organisation. An application for a trial permit can be submitted for a product that has not been approved in Finland. Products that have been approved for trial use are not widely available on the market. Permission can also be sought for a product previously approved in Finland, in which case the application concerns a new purpose for the product. The party holding a permit for trial use selects the areas to be sprayed based on the occurrence of the pest to be controlled. The application for a change to the instructions of use is submitted by the party with marketing authorisation for the product, and the product is normally available on the market.

Regardless of the type of permit, the applicant must demonstrate through reliable research results and a risk assessment that the risks posed by the aerial spraying of the plant protection product to human health and the environment are smaller than those arising from traditional methods of applying the product.

The Finnish Safety and Chemicals Agency assesses the special health and environmental risks from drone spraying on a case-by-case basis, based on the material submitted by the applicant. The applicant may be required to provide further information during permit processing. As no generally approved risk assessment method yet exists in this field, the information supplied by the applicant must be assessed individually for each case. For now, drone spraying can only be approved for trial use. The application can be approved only if the risks are at an acceptable level. In testing operations, risks can be managed using more stringent methods than normally, including adequate safety distances. The applicant will be notified of the decision on the permit for drone spraying of a plant protection product. The applicant will be invoiced in accordance with the price list of the Finnish Safety and Chemicals Agency. This calls for a revision of the decree on the charges payable to the Finnish Safety and Chemicals Agency.

2. *Registration as a UAS operator and authorisation to operate in the "specific" category*

Drone operators must register as UAS operators in Traficom's register. To obtain an operational authorisation in the "specific" category, the operator must submit a risk assessment (SORA *Specific Operations Risk Assessment* or PDRA *Pre-Defined Risk Assessment*) of drone spraying to the Finnish Transport and Communications Agency (Traficom). The applicant can carry out the risk assessment independently or use the consultancy services available. Traficom processes the risk assessment and the application and makes a decision based on the information supplied by the applicant. Traficom invoices drone operators in accordance with its valid price list.

3. *Two-stage process for an exemption to drone spraying*

We propose that the Finnish Safety and Chemicals Agency be the competent authority mentioned in the framework directive for the sustainable use of pesticides (128/2009/EY)[3]. The exemption for aerial spraying

[3] Directive 2009/128/EC of the European Parliament and of the Council establishing a framework for Community action to achieve the sustainable use of pesticides. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0128&from=EN.

comprises a planning stage and an implementation stage (Figure 3). According to Article 9, paragraph 4 concerning aerial spraying in the framework directive, a professional user must present Tukes with **a) an application for the approval of its aerial spraying plan.** In the implementation stage, the applicant must submit to Tukes its **b) application for aerial spraying** in accordance with the approved plan in due time before spraying is to take place. Any significant changes to the information supplied with the aerial spraying plan must be included in the application. The framework directive allows for the request for aerial spraying to be processed as a notification (Article, paragraph 4, subsection 2).

3 a) Application for the approval of the aerial spraying plan and its processing by the Finnish Safety and Chemicals Agency

The following requirements laid out in Article 9, paragraphs 2 and 3 of the framework directive must be included in the application for the approval of the aerial spraying plan:

1. Drone spraying is safer for humans and the environment.
2. The plant protection product has explicit approval for aerial spraying.
3. The operator carrying out the aerial spraying has a certificate of training in plant protection.
4. The required aviation permits are in order, as demonstrated by a report from Traficom indicating that the operator is registered as a UAS operator and has an operational authorisation for aerial spraying of plant protection products in the "specific" category (PDRA or SORA).
5. Specific risk management measures to protect bystanders. The area to be sprayed may not be in close proximity to residential areas.
6. The sprayer must be equipped with the best available technology to reduce spray drift.

The application concerning the aerial spraying plan must also include provisional information about the practical implementation of spraying: the date and time of spraying, the plant protection products to be used, as well as the plants and the area to be sprayed. In addition, the application must also specify:

- Special (weather) conditions during which spraying is permitted related to, for example, wind force, brightness and rain conditions.
- The planned measures for providing advance warning to residents and bystanders and for protecting the environment in close proximity to the area to be sprayed.
- Information concerning the inspection of the drone used (framework directive[3] Article 8) or that the drone sprayer was purchased less than five years before the spraying.

The Finnish Safety and Chemicals Agency will process the application and request further information from the applicant, if required. The Finnish Safety and Chemicals Agency will assess whether the legal requirements are met, allowing an exemption to be granted for the aerial spraying of plant protection products with a drone sprayer. If the application is approved, the permit granted by the Finnish Safety and Chemicals Agency will describe the conditions under which drone spraying is allowed, as well as the schedules for permitted spraying. The Finnish Safety and Chemicals Agency will submit the decision to the applicant and invoice the applicant in accordance with its price list, which will call for a revision of the decree on the charges payable to the Finnish Safety and Chemicals Agency.

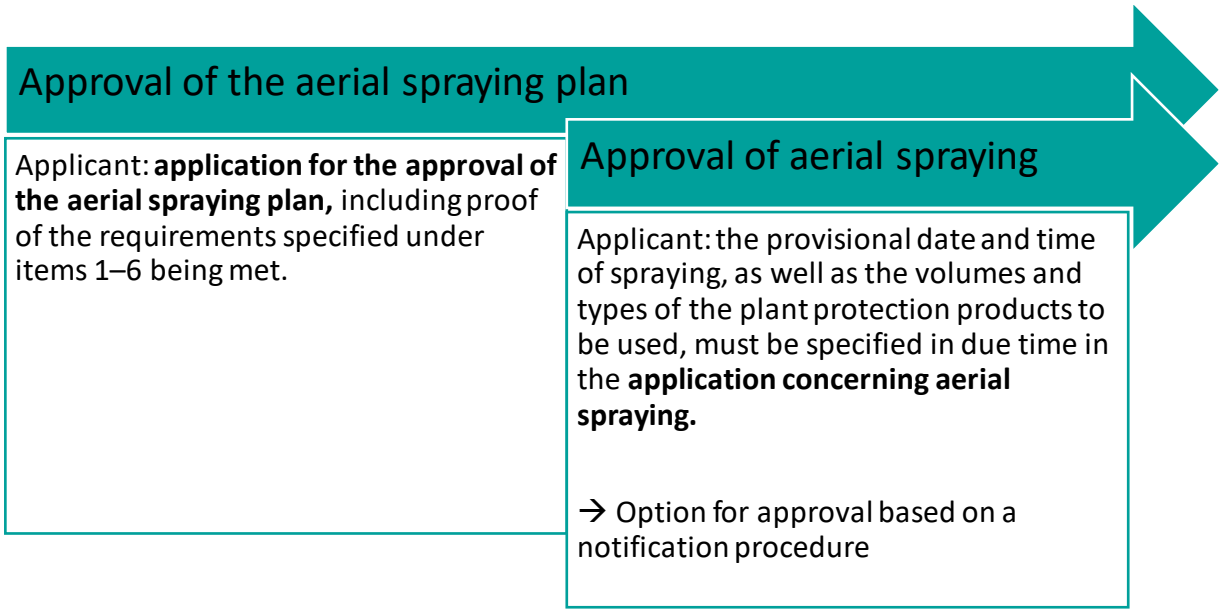

Figure 3. The application process for an exemption concerning drone spraying has two stages.

3 b) Processing of application for aerial spraying at the Finnish Safety and Chemicals Agency

When the aerial spraying plan has been approved, the drone operator applies for approval of the aerial spraying operation. Member States may provide that applications for aerial spraying in accordance with an approved spraying plan, for which no answer was received within the time period laid down by the competent authorities, shall be deemed to be approved. This part of the process can be handled as a notification procedure, and it would be sensible to do so. The Finnish Safety and Chemicals Agency can refuse to grant the permit if the application for aerial spraying contains a significant deviation from the approved aerial spraying plan, such as a clearly larger area or a plant protection product different from the one included in the plan. The Finnish Safety and Chemicals Agency publishes information about approved aerial spraying on its website at tukes.fi.

2.3. Cost impacts

The permit procedure for the aerial spraying of plant protection products requires the cooperation and supervision of several authorities. As existing practices, the UAS registration related to aviation and the risk assessment related to the permit procedure will not incur costs for the establishment of new activities. In contrast, the risk assessment related to the permit for aerial spraying of plant protection products will call for new procedures and internal ways of working at the Finnish Safety and Chemicals Agency, as well as the preparation of new guidelines and the adaptation of existing guidelines, all of which may incur additional costs. The costs for risk assessment and other official duties related to the permit procedure can be recovered, and the price list of the Finnish Safety and Chemicals Agency will be updated accordingly.

2.4. Comments from the steering group

The project's steering group included representatives from the Ministry of Agriculture and Forestry, the Finnish Transport and Communications Agency, the Natural Resources Institute Finland, VTT Technical Research Centre of Finland, Kasvinsuojeluteollisuus ry, Puutarhaliitto ry and the Finnish Safety and Chemicals Agency. The steering group held two meetings during the project. The steering group supports the proposal of granting exemptions for drone use primarily for trial purposes, which have been found to be the safest at this stage. The application of plant protection products with drones involves numerous

aspects which are not yet adequately understood. Trials, research and innovations are deemed important, and legislative amendments are required. A national solution is complex and is expected to be temporary. The proposed legislative amendment applies widely to the exemption procedure, without restrictions on the purposes of use, but in practice, inadequate knowledge and the lack of risk assessment methods currently limit the use to trials. In the plant protection industry, producers have no real interest to apply for drone spraying permits for their products in Finland, if legislation in other European countries does not progress in this respect.

It is hoped that in the future, the EU's legislative framework will offer more flexible options for the use of drone sprayers in plant protection operations. The goal is to have the framework directive treat drone spraying separately from spraying carried out from helicopters and aircraft. Finland must communicate this message at the political level and in EU-level working groups to the Commission's representatives, highlighting the importance of updating regulation and making the requirements on drone spraying more reasonable. Moreover, access must be secured to the required information about drift, and the European Food Safety Authority should develop tools suitable for the risk assessment of drone spraying, for example, to model exposure in terms of health and the environment. The key message of the project was conveyed to representatives of the Commission and Member States during discussions related to the work on amendments to the framework directive on 25 February 2021.

3. Valid legislation

The use of drone sprayers for the application of plant protection products is not permitted in Finland[4]. The European Commission treats drones as aerial vehicles[5] and prohibits the application of plant protection products from an aerial vehicle in directive 128/2009/EC on the sustainable use of pesticides. The directive permits exemptions to this prohibition, provided the risks to human health and the environment are lower than those arising from conventional methods of application. In the EU, the use of drone sprayers has been investigated in, for example, France and Germany. A survey conducted by the Finnish Safety and Chemicals Agency among EU Member States indicated that the potential of drones in plant protection use has been identified in many countries.

3.1. Drone spraying is aerial spraying, derogations in the directive

The European Commission considers[6] the use of unmanned aerial vehicles for the application of plant protection products to be aerial spraying. According to the Commission, Member States can permit drone spraying in accordance with Article 9(2) of the framework directive if the purpose is to develop the use of drones for spraying plant protection products in precision farming. Exemptions granted for such use must be supervised. In aerial spraying, the risks to health and the environment must be lower than those of land-based application.

The framework directive on the sustainable use of pesticides prohibits aerial spraying of plant protection products. Aerial spraying may be allowed in special cases if no viable alternative exists or if the impacts on human health and the environment are lower than those arising from land-based application. The operator carrying out aerial spraying must request approval for the operation in due time and include provisional information about the date and time of spraying and the product to be used in the application. The risks

[4] Act on Plant Protection Products (*Laki kasvinsuojeluaineista)* 1563/2019. https://www.finlex.fi/fi/laki/ajantasa/2011/20111563.

[5] EC DG Sante 2017, Ref. Ares(2017)6111366 - 13/12/2017, Application of pesticides by drones, Directive 2009/J28/EC on the Sustainable Use of Pesticides (SUD).

[6] European Commission 2017: Application of pesticides by drones, Directive 2009/J28/EC on the Sustainable Use of Pesticides (SUD). Ref. Ares(2017)6111366 - 13/12/2017.

arising from the plant protection product in aerial spraying must be assessed, and the product must have been authorised for use in aerial spraying.

To manage the risks of aerial spraying, the best available technology must be used to reduce spray drift, and measures must be adopted to protect residents and bystanders. Operators carrying out aerial spraying must hold relevant qualifications, and companies offering aerial spraying must be authorised by the aviation authority. The competent authority must specify the required measures for providing advance warning to residents and bystanders and for protecting the environment in close proximity to the area to be sprayed. The authorities must keep a record of permit applications and permits, and make available to the public the information on the area to be sprayed, the date and time of spraying, as well as the plant protection product to be sprayed.

3.2. Act on Plant Protection Products

The Act on Plant Protection Products[4] prohibits the aerial spraying of plant protection products, with the exception of two special cases. Pursuant to the Act, an exemption may be granted to control pests, pursuant to the Act on the Protection of Plant Health[7], in which case the decision on the exemption is made by the Finnish Food Authority. An exemption may also be granted under the Forest Damages Prevention Act[8] to prevent extensive forest damage to forest trees using a biological plant protection product. In this case, authorisation is granted by the Ministry of Agriculture and Forestry, on the presentation of the Finnish Forest Centre. The Ministry of Agriculture and Forestry has issued a decree on aerial spraying[9], with regulations on the methods to be adopted and the notifications to be made.

The provisions of the Act on Plant Protection Products concerning the prerequisites for aerial spraying (section 21) and the performance of aerial spraying (section 22) should be applied to drone spraying, with the amendments proposed in chapter 2.1. The decree of the Ministry of Agriculture and Forestry on aerial spraying should be amended with more detailed procedures for performing drone spraying. **The requirements for drone spraying should be assessed and formulated to ensure that small-scale treatment does not call for advance measures of unreasonable proportions. This is not easy under current legislation, but an amendment to the framework directive is expected to alleviate the situation.**

3.3. Permission to use drones to spray plant protection products for trial purposes

A permit for trial use is a good way to obtain information about the viability of drones for spraying plant protection products and about the restrictions set for the methods. Only plant protection products approved by the Finnish Safety and Chemicals Agency are allowed to be used in Finland. If the plant protection product or its planned use have not been authorised in Finland, the applicant may seek a permit for trial use to determine whether the product or use are suitable for the Finnish environment and cultivation method. A permit for trial use enables the required surveys to be carried out. A trial permit is also required to carry out testing on an authorised product used for a new purpose.

At present, no plant protection product has been authorised for aerial spraying in Finland. A trial permit can be used to test drone spraying with an unauthorised product or for an unauthorised purpose.

Under the Act on Plant Protection Products, the Finnish Safety and Chemicals Agency has been given the right to grant permits for trials carried out for research and development purpose, which require an

[7] Act on the Protection of Plant Health 702/2003. https://www.finlex.fi/fi/laki/ajantasa/2003/20030702.
[8] Forest Damages Prevention Act 1087/2013. https://www.finlex.fi/fi/laki/ajantasa/2013/20131087.
[9] Decree of the Ministry of Agriculture and Forestry (8/2012) on the aerial spraying of plant protection products (in Finnish). https://finlex.fi/fi/viranomaiset/normi/2012/39162

unauthorised plant protection product to be released into the environment. Detailed requirements concerning trial and research operations are provided in the decree of the Ministry of Agriculture and Forestry (9/2012)[10] on the approval of testing facilities for plant protection products and on trial and research operations.

The wording does not cover every case of the EU regulation on plant protection products (EC No 1107/2009), as Article 54 of the regulation mentions the release into the environment of an unauthorised plant protection product as well as the *unauthorised use of a plant protection product*. To ensure that drone spraying can be used for trials, one of the questions that needs to be answered is whether legislation should also include unauthorised use as a target of testing and research. Under our interpretation, the aerial application of plant protection products using drone sprayers qualifies as unauthorised use.

Various conditions for protecting health and the environment can be included in the permit for trial use or the product's instructions for use. For example, restrictions on drone spraying could concern the purpose and area, flight height, maximum permitted wind speed, as well as safety distances to water bodies, residential areas and public roads. Where applicable, the restrictions concerning aerial spraying specified in the decree of the Ministry of Agriculture and Forestry (8/2012) could be used, or if required, the requirements of the decree can be updated to better address drone spraying.

3.4. Regulations concerning unmanned aviation

Legislation related to unmanned aviation is undergoing changes. After the transition period, and no later than 1 July 2021, the EU implementing regulation (EU) 2019/947[11] will be applied. Drone spraying can likely be performed in accordance with the requirements of the "specific" category, which calls for an operational authorisation. The authorisation can be granted based on the Specific Operations Risk Assessment (SORA) carried out by the applicant. Predefined Risk Assessments (PDRA) can also be used. Risk assessment examines risks on land and in the air, including the reliability of equipment operations. If the area to be sprayed is far from humans and airports, authorisation for well-planned drone spraying operations could probably be granted from the perspective of aviation.

According to Article 6 of the implementing regulation, operations must be carried out in the "certified" category if they involve the carriage of dangerous goods that may result in a high risk for third parties in case of accident. The "certified" category calls for strict requirements on the equipment used and for aviation operations at large. In aviation, dangerous goods are articles or substances that are capable of posing a hazard to health, safety, property or the environment in the case of an incident or accident and that the unmanned aircraft is carrying as its payload, including in particular[12]:

a. Explosives (mass explosion hazard, blast projection hazard, minor blast hazard, major fire hazard, blasting agents, extremely insensitive explosives)
b. Gases (flammable gas, non-flammable gas, poisonous gas, oxygen)
c. Flammable liquids (flammable liquids, combustible, fuel oil, gasoline)
d. Flammable solids (flammable solids, spontaneously combustible solids, dangerous when wet)
e. Oxidising agents and organic peroxides
f. Toxic and infectious substances

[10] Decree of the Ministry of Agriculture and Forestry (9/2012) on the approval of testing facilities for plant protection products and on trial and research operations (in Finnish) https://finlex.fi/fi/viranomaiset/normi/2012/39163

[11] Commission implementing regulation (EU) 2019/947 on the rules and procedures for the operation of unmanned aircraft https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019R0947.

[12] International Civil Aviation Organization ICAO Doc 9284, Technical Instructions for the Safe Transport of Dangerous Goods by Air, edition 2017-2018, ISBN 978-92-9258-034-6, 1056 p.

g. Radioactive substances
h. Corrosive substances
i. Other dangerous substances and articles, including those harmful to the environment.

Based on the properties listed, many plant protection products do not cause a risk for aviation, and operations should therefore be carried out in the "certified" category. If the plant protection products that match the list are eliminated, operations can be carried out in accordance with the "specific" category. Moreover, the products to be sprayed are diluted prior to application, meaning that their hazard classification is not necessarily the same as that of the concentrate. Nevertheless, as the risks related to aviation are assessed on a case-by-case basis, the category of operations cannot be assured in advance. If required, the risks from operations can be mitigated through risk management methods.

4. Potential uses in Finland

In connection with the project, a small workshop for stakeholders was organised on 22 April 2021. Discussions at the workshop focused on potential uses for drone sprayers. The goal was to identify the first purposes that drone sprayers were most likely to be used for. The participants found that drones are already suitable for many agriculture tasks such as sowing, observation of pests and crops, as well as fertilisation. The following uses came up in connection with the spraying of plant protection products:

- Targeted measures in forestry: application of elk repellent in sapling stands
- Spraying of small, disperse areas of golf courses and control of snow moulds
- Horticulture in general
- Patch treatment, such as the precision control of wild oat, targeted control of thistle and sow thistle, necessitating an optimised time of use in relation to the preservation of growth, as well as the removal of couch grass from mature crops
- In orchards, treatment of small areas, more accurate targeting of the canopy
- Top-down spraying of raspberry crops
- In strawberry crops, drones may be faster, but are they as accurate as strip spraying?
- Strip farmed plants
- Treatment of wet growth sites (e.g. control of potato late blight)

The proposed uses are still hypothetical. From the perspective of authorisation, the risks are always assessed by individual product and use. For example, uses with too wide a scope are not acceptable due to environmental considerations.

The proposed uses are in line with the more extensive workshop discussion organised in the spring of 2020. At the time, the participants also focused on future visions, in which crops would be observed by drones equipped with sensitive sensors, and based on their observations, autonomous flocks of drones or combinations of drone and tractor would carry out plant protection measures.

The use of drone sprayers to control moss on roofs also came up in the discussions at the project workshop. This type of moss control involves the application of biocides[13], which are regulated by other legislation. The application of biocides using drones is not allowed in Finland, as the risks of drone spraying have not been assessed, and drone spraying has not been authorised as a form of application in the instructions.

[13]Finnish Safety and Chemicals Agency 2021 Biocides. https://tukes.fi/en/chemicals/biocides (Accessed: 7 May 2021).

4.1 The importance of the point of reference

When assessing the potential uses of drone sprayers, it is essential to determine the point of reference. The permit procedure will depend on the individual case, and health and environmental risks will always be compared to existing practices. The following chapter discusses cases from around the world. In them, a better alternative to traditional uses has been sought for various reasons, for example, to address difficult access to the area with a tractor sprayer, to improve the occupational safety of operators using knapsack sprayers, to replace aerial spraying carried out by manned aircraft with a safer and more environmentally friendly alternative or to reduce spray drift compared with the spraying of trees and shrub by air assistance.

Early in the adoption of drone spraying, it may be easier to authorise low-risk or biological products. For example in France, only products authorised for organic production are allowed to be used in the trial use of drone spraying. However, in Finland, products that may irritate the respiratory organs, skin or eyes have also been authorised for use in organic production. A product approved for organic production is not automatically an innocuous substance.

5. Use of drone sprayers in the EU Member States and elsewhere in the world

The following discussion provides a cross-section of the results from a survey that the Finnish Safety and Chemicals Agency conducted among EU Member States in 2020. It is followed by an overview of the situation in a few Member States and other parts of the world in 2021. The information in this chapter is based on email communication between authorities, unless stated otherwise.

5.1. Finnish Safety and Chemicals Agency survey among EU Member States in 2020

In the spring of 2020, the Finnish Safety and Chemicals Agency requested members of the working group for the Commission's framework directive on the sustainable use of pesticides to share their experiences of drone spraying. Twelve of the participating countries, including Norway, submitted their answers. The use of drone sprayers has aroused interest in the Member States, but a few of the countries had not conducted discussions on the topic. The Member States acknowledge that the technology for drone spraying is developing quickly and is suitable especially for the needs of precision farming. In some countries, drone sprayers have been used for the application of biocides and biostimulants. Research on drone use is or has been underway in some of the Member States.

- In France, research focuses on the benefits from the use of drone sprayers compared with land-based application. The goal is to improve occupational safety and reduce accidents at work. The cases studied include vineyards and banana plantations on steep slopes.
- In Luxembourg, after a three-year experiment, the effectiveness of drone spraying was found to be equivalent to that of helicopter spraying but not as good as tractor spraying.
- In Germany, studies are being conducted on the use of drone spraying for precision farming in pomiculture, as well as on the effectiveness and scope of spraying in viticulture and spray drift from drones.
- In Finland and Portugal, research has focused on the identification of pests using drones.

The use of drone sprayers for the application of plant protection products is prohibited in 11 Member States and in Norway, but discussion on legislative amendments has been launched in some Member States:

- An amendment to legislation is underway in Hungary.
- In Luxembourg, drone sprayers are not treated as aerial vehicles, and they are already in use in the country.

- In Spain, a working group is discussing operating methods and the conditions for authorisation to enable the competent authorities to grant exemptions to the ban on aerial spraying.
- In France, the results of a three-year project indicate a potential need for amendments to legislation.

5.2. Spain

In Spain, legislation prohibits aerial spraying and only allows it in special cases, in accordance with the framework directive[14]. Drones can now be used for spraying. The requirements for drone spraying have been specified in guidelines concerning aviation legislation related to drone spraying, the authorisation of aerial spraying of plant protection products and the testing of drone sprayers[15]. The operator carrying out drone spraying must be entered in the register of plant protection professionals (ROPO)[16] and complete 90-hour training covering the special requirements for aerial spraying. Training for drone spraying is already available[17]. Drone sprayers must be entered in the register for application equipment (ROMA)[18] and tested regularly (ITEAF)[19]. Under aviation legislation (AESA), the pilot/company must be registered and complete a 60-hour training for professional drone operators. Training is subject to a fee. In Spain, legislation is implemented by each autonomous community, which may lead to regional differences in the additional conditions and permit processes concerning drone spraying.

5.3. France

France has prohibited the aerial spraying of plant protection products, but permits biocides to be applied with drone sprayers. The possibility to use drone sprayers to apply plant protection products has been sought especially for vineyards and banana plantations on steep slopes. A three-year trial of drone spraying on steep slopes (>30%) was approved by law (Article 82 of the act 2018/938[20]). Under the act, the ministries of agriculture, health and the environment must approve individual trial arrangements. The trial's approval process, the test plan and the safety requirements are described in the ministries' decree[21]. Trial operations must also meet the legislative requirements for other drone use. France received the first permit applications for the use of drones to spray plant protection products in 2020. The permits were

[14] Real Decreto 1311/2012, de 14 de septiembre, por el que se establece el marco de actuación para conseguir un uso sostenible de los productos fitosanitarios. https://www.boe.es/buscar/pdf/2012/BOE-A-2012-11605-consolidado.pdf.
[15] Ministerio de Agricultura, Pesca e Alimentación and Agencia Estatal de Seguridad Aérea 2018: Nota informativa - Tratamientos aereos con drones con productos fitosanitarios. https://www.mapa.gob.es/es/agricultura/temas/sanidad-vegetal/180816notainformativatratamientosaereoscondrones--aesa_tcm30-57933.PDF.
[16] Ministerio de Agricultura, Pesca e Alimentación and Agencia Estatal de Seguridad Aérea 2021: Registro oficial de productores y operadores de medios de defensa fitosanitaria (ROPO) https://www.mapa.gob.es/es/agricultura/temas/sanidad-vegetal/productos-fitosanitarios/ropo/.
[17] Iberfdrone 2021: Curso Piloto Aplicador Fitosanitario Aéreo. https://iberfdrone.es/piloto-aplicador-fitosanitario-aereo-drone/
[18] Ministerio de Agricultura, Pesca e Alimentación 2021: Registro de maquinaria agrícola, https://servicio.mapama.gob.es/regmaq/buscar.wai.
[19] Ministerio de Agricultura, Pesca e Alimentación 2021: ITEAF: Inspección de Equipos de Aplicación de Productos Fitosanitarios. https://www.eurocontrol.es/inspeccion-reglamentaria/servicios/iteaf-inspeccion-de-equipos-de-aplicacion-de-productos-fitosanitarios/.
[20] Article 82 - LOI n° 2018-938 du 30 octobre 2018 pour l'équilibre des relations commerciales dans le secteur agricole et alimentaire et une alimentation saine, durable et accessible à tous (1). https://www.legifrance.gouv.fr/loda/article_lc/LEGIARTI000037549189/2018-11-02.
[21] LégiFrance 2019: Arrêté du 26 août 2019 relatif à la mise en œuvre d'une expérimentation de l'utilisation d'aéronefs télépilotés pour la pulvérisation de produits phytopharmaceutiques. https://www.legifrance.gouv.fr/loda/id/JORFTEXT000039191505/.

granted to vineyards and banana cultivation, but drones were only used in vineyards. Only products authorised for organic production were allowed in the trials. Research has also been carried out by spraying dyed tracer.

5.4. Norway

Norway allows the use of drone sprayers for trials, and it is possible to seek permits for aerial spraying on steep slopes. A few products have been authorised for aerial spraying, and they have been applied from helicopters, for example. Trials of drone spraying are not allowed closer than 200 metres from residential areas, and in public spaces, notification of spraying must be provided in due time with warning signs. The results from Norway indicate that the spray drift from drone sprayers is smaller than that from helicopter sprayers. However, drone sprayers are not a better alternative compared with boom sprayers. Regarding spraying technology, it is essential to reduce the spray drift to enable a wider use of drone sprayers in field cropping.

5.5. Germany

Germany allows, under special permit, the use of aerial vehicles for spraying plant protection products on steep mountain slopes in viticulture and for treetops in forestry. Aerial spraying is not permitted in field cropping[22]. As drone spraying counts as aerial spraying, the same restrictions of use apply to it.

The authorisation of plant protection products used in drone spraying is handled by four federal authorities: The Federal Office of Consumer Protection and Food Safety (Bundesamt für Verbraucherschutz und Lebensmittelsicherheit BVL) assesses the residues and food safety, the Federal Institute for Risk Assessment (Bundesinstitut für Risikobewertung BfR) assesses the risks to employees and bystanders, the German Environment Agency (Umwelt Bundesamt UBA) assesses environmental risks and the Julius Kühn Institute (JKI) assesses biological effectiveness. The JKI also conducts practical trials and technical tests to ensure the operations of spraying equipment before the equipment can be approved for use. To date, two drone sprayer models have been authorised for the application of products. Practical trials last for at least twelve months, and this has proved to be problematic in view of the rapid development of drone sprayers.

Authorisation for drone spraying has been sought for several plant protection products used on vineyards located on steep slopes. The inadequate research data on the atmospheric concentration of plant protection products has been found to be problematic when assessing the health risks of substances used in drone spraying. Assessments are made based on existing spray drift data from the ground sediment, adjusted by safety coefficients. The first product authorisations for drone spraying are expected in 2021.

The JKI is also testing the spray drift of plant protection sprayers and the impact that different application techniques have on spray drift. The research results have been used to calculate the basic drift values for the worst possible alternative (90th percentile), with which new technologies can be compared. Separate results have been published for field crops, fruit crops, hops and vines[23], [24]. In recent years, German research has also focused on the spray drift from drone sprayers in viticulture and field crops. According to

[22] Bundesministerium der Justiz und Verbraucherschutz 2012: Gesetz zum Schutz der Kulturpflanzen (Pflanzenschutzgesetz - PflSchG) § 18, https://www.gesetze-im-internet.de/pflschg_2012/__18.html.

[23] Rautmann D., Streloke M., & Winkler R. 2001: New basic drift values in the authorization procedure for plant protection products. Workshop on Risk Assessment and Risk Mitigation Measures (WORMM), vol. 13. 3–141. https://www.researchgate.net/publication/284496304_New_basic_drift_values_in_the_authorization_procedure_for_plant_protection_products.

[24] Rautmann D., Ganzelmeier H., Spangenberg R., Streloke M., Herrmann M., Wenzelburger H.-J. & Walter H.-F. 1995: Studies on the spray drift of plant protection products.

preliminary research results, the drift from drone spraying is smaller than that of air-assisted sprayers used on vineyards, if the drone sprayer is equipped with air-assisted nozzles that reduce drift. Compared with helicopters, the drift from drone sprayers is clearly smaller. However, in the case of field crops, the drift from drone sprayers is larger than that from boom sprayers. The use of drones for the identification of pests and subsequent patch treatment would enable spray drift to be reduced to a safe level when treating field crops.

In Germany, the weight limit for drone sprayers will probably be set at 150 kg. Insecticides have been either avoided or used very selectively in drone spraying carried out in wine-growing areas. Other control methods have also been used.

5.6. Switzerland

Switzerland has allowed the use of drone sprayers in viticulture and pomiculture on steep slopes, where conventional spraying equipment drawn by tractor has been impossible to use. Crops like these have traditionally been treated with knapsack sprayers. The safety distance to the environment and bystanders is five metres, that is, the same distance in use for the traditional tractor spraying of trees and shrubs. Drones have been allowed for field crops and more widely in viticulture and pomiculture since spring 2019. The safety distance for field crops is twenty metres. In Swiss studies, the sprayers have been equipped with drift-reducing nozzles, which has led to regrettably low spraying efficiency, and drone spraying is recommended as a supplement to other spraying methods. Crop penetration and coverage must be improved to achieve more efficient spraying[25].

In Switzerland, the use of drone sprayers is based on advance authorisation. The drone sprayer model must be approved before it can be used to apply plant protection products. Once approved, the model can be used for spraying. Testing corresponds to that of the sprayer: the device components, lateral homogeneity of spraying, droneport and navigation are tested. The navigation test determines the device's capacity to carry out the predesigned assignment. During the test, the drone must cover a specific track under supervision. The air flow caused by the propellers is also measured at distances of ten and twenty metres, and the results are used to model the potential drift. The measurements are compared with the air stream generated by a conventional sprayer compliant with the ISO 22369 standard. If the drone's air stream is smaller, the conclusion is that the resulting spray drift does not pose a larger risk of drift than the other methods in use.

Switzerland has set the maximum weight of drones at 150 kg. The limit appears to be based on an obsolete weight limit for aircraft. Under former aviation legislation, aircraft weighing more than 150 kg would have required a pilot's licence (Andreas Herbst 12 April 2021). In Switzerland, drone sprayer models are tested once before they are authorised for use, and drone sprayers in use are tested every three years[25]. In 2020, Switzerland had 25 drone sprayers in use, and they were used to spray approximately 150 hectares. Substantial growth is expected in 2021[26].

5.7. United States

In the US, California approved the use of drones for the application of plant protection products in 2015, and other states have followed suit since. The Federal Aviation Administration (FAA) has various registration and certification requirements in place for the pilot, drone sprayer, agricultural aviation and

[25] Apter, N. 2021: The use of drones in Switzerland for PPT applications. Presentation at the 25 February 2021 meeting of the working group for the Commission's framework directive on the sustainable use of pesticides.
[26] Dubuis P-H. et al 2020: Drones application study in Switzerland. 6th International Akademie Fresenius Conference "Worker, Operator, Bystander and Resident Exposure and Risk Assessment".

the application of plant protection products[27]. Legislation on small drones was revised in 2016, but the status of drones remains unclear in legislation concerning aerial spraying and requires the application of exceptions[28]. In the US, drone sprayers mainly replace airplanes and helicopters in spraying operations. The wider use of drones likely reduces the drift of plant protection products, compared with other aircraft used.

5.8. Drone/UAV subgroup of OECD

In 2019, prompted by the rapid development and increasing use of drones, the Organisation for Economic Co-operation and Development (OECD) established a project-based drone/UAV subgroup under its working group for pesticides. The goal of the subgroup was to identify aspects typical of drone technology that influence the types of risks involved. These were to be compared with existing risk assessment methods for plant protection products. In addition, the group was tasked with identifying any additional requirements and information gaps related to the technology, as well as with proposing a procedure for managing risks. In 2020, the group conducted two surveys among authorities, companies and research groups to examine publications and ongoing research concerning drone sprayers. The group's report was presented at the meeting of the OECD's Pesticide working group in July 2021, but it has not yet been published. The report data can later be used to, for example, review the requirements for drone sprayers.

6. Equipment requirements for drone sprayers

The equipment requirements for plant protection sprayers are specified in directive 2009/127/EC amending directive 2006/42/EC with regard to machinery for pesticide application[29]. The directive requires the manufacturer of the equipment used for the application of plant protection products to take into consideration and ensure the performance of control devices, the safe filling and emptying, the appropriate application rate and the application of plant protection products only on the target area. Under the directive, it must also be possible to clean, service and inspect the application device safely. The application device must also have markings indicating the filters suitable for the equipment, as well as the option of indicating the plant protection product used on the device. Manufacturers of application equipment must also adhere to the requirements of directive 2006/42/EC on machinery.

Manufacturers can assume their spraying equipment satisfies the directive's requirements, if they apply the harmonised standards. A general standard EN ISO 16119-1 is available for sprayers, parts of which also apply to drone sprayers. EN ISO 16119-1 does not specify requirements for device types. Unfortunately, no harmonised standard yet exists for drone sprayers.

However, standardisation efforts to specify requirements for drones are underway at the International Organization for Standardization (ISO). The ISO working group TC 23/SC 6/WG 25 is preparing the ISO 23117 set of standards. The standardisation work is in early stages, and the completion of the standards is expected to take around three years. It is not yet known whether the new standards will also be applicable as harmonised standards. The drone and application device will be treated as a single unit in the standardisation work, meaning that the aerial vehicle is considered to be part of the application device. Such units are called Unmanned Aerial Spraying Systems (UASS).

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[27] Fulton J., Wiegman C., Ozkan E., and Shearer S. 2020: Spraying with drones – Ohio Ag Net | Ohio's Country Journal. https://ocj.com/2020/04/spraying-with-drones/.

[28] Petty, R. Drone use in aerial pesticide application faces outdated regulatory hurdles. Harvard Journal of Law & Technology. https://jolt.law.harvard.edu/assets/digestImages/Digest_Petty_Ryan_Note_Fall17_Final.pdf.

[29] Directive 2009/127/EC of the European Parliament and of the Council amending Directive 2006/42/EC with regard to machinery for pesticide application. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009L0127.

Although the standardisation work has not yet been completed, some of the details are known. The tank or its protective structure must withstand a fall intact. The tank must be designed to attenuate splashing. The tank must be equipped with a pressure equalizing device that lets air into the tank as the amount of spraying liquid decreases. No liquid may leak from the tank. It must be possible to close the lid of the tank without tools, and the tank must be safe to fill and empty. The filling hole must comply with the ISO 9357 standard, and in the case of demountable tanks, have a minimum diameter of five (5) centimetres.

Nozzles must have drip prevention valves that prevent dripping within one (1) second from the end of spraying. The nozzles must ensure a steady and appropriate application of the substance, but they do not need to be evenly distributed. However, the distance between the outermost nozzles must not exceed 75% of the drone's total width.

Drones must ensure a homogeneous spraying pattern, which means they must be able to adjust the volume of the sprayed product to their velocity so that the volume sprayed per area unit remains constant. Drones must also ensure the appropriate distance (height) to the area sprayed. To satisfy this requirement, drones must typically include a global navigation satellite system (GNSS), as well as a separate sensor for measuring height/distance.

The measurements and methods required to ensure homogeneous spraying will be described in the ISO 23117-2 standard. Unfortunately, no information is currently available on it. The standard's completion is expected to take another three years. For now, other measures must be adopted to ensure the homogeneity of spraying and spray drift.

It is important to describe and standardise the properties of drone sprayers because this information is needed when assessing the risks of using a plant protection product in aerial spraying. The properties of the drone sprayer can affect, for example, the user's exposure and the spray drift of plant protection products. If the risk assessment is based on specific assumptions of the equipment and its performance, it is important to ensure that the actual spraying is carried out with corresponding or better equipment. The minimum requirements for drones should be specified in a decree of the Ministry of Agriculture and Forestry or in instructions issued by the Finnish Safety and Chemicals Agency to ensure the minimum standard of equipment. Where justified, the restrictions may derogate from the specifications of ISO 23117-1. There are, for example, curved booms, with a width exceeding 75% of the overall width of the drone, that are intended for spraying berry bushes. The purpose and design of these booms may be used to justify their use in special cases. Derogations must be reviewed when seeking approval for a plant protection product, and derogations should be recorded in the instructions for the plant protection product.

For aerial spraying to be authorised, the drone operator must first obtain authorisation to operate a drone for the purpose of applying plant protection products. According to the EU's implementing regulation concerning drones[11], the aerial spraying of plant protection products comes, as a minimum, under the "specific" category, which requires an operational authorisation. Applications for an operational authorisation require a risk assessment based on the scenarios provided by the European Union Aviation Safety Agency (EASA) or a risk assessment provided by the applicant[30]. The operational authorisation addresses risks related to the operation of drones and the carriage of goods, the assessment of which is handled by the Finnish Transport and Communications Agency. The requirements of the operational authorisation exceed many of the requirements related to plant protection products alone, such as those concerning emergency stopping and landing, tank protection and the maximum (transfer) flight height. This

[30] TRAFICOM Droneinfo, EU:n dronesäännöt https://droneinfo.fi/en/eu-drone-regulation

means that the risk assessments related to plant protection products can focus solely on the handling and application of plant protection products.

It is not easy to conduct the risk assessment required for an operational authorisation. As was indicated at the project's stakeholder workshop, operators have some experience in applying for operational authorisation in the "specific" category. In addition, some consulting firms can also help users apply for authorisation.

7. Inspection of existing drone sprayers

There are currently no standards for the aerial spraying of plant protection products with drones that would address the environmental requirements of new drones and the inspection of existing spraying equipment. Under the framework directive and legislation, the equipment used for the aerial spraying of plant protection products must be inspected. No inspection standard for drone sprayers is currently under preparation, but an ISO working group is preparing requirements for new spraying equipment[31].

Existing inspection instructions and standards must be applied to spraying equipment mounted on aerial vehicles. Where possible, the instructions for the inspection of spraying equipment prepared by the SPISE working group (*Standardised Procedure for the Inspection of Sprayers in Europe*)[32] can be applied.

In accordance with valid inspection requirements[33], drone sprayers come under category F (spraying equipment mounted on aerial vehicles) or category G (other spraying equipment), which means they must be first inspected five years after their introduction, and subsequently every three years. No suitable inspection guidelines are currently available in Finland. The standard EN ISO 16122-1 can be applied for inspections. In every other respect, inspections must be carried out in accordance with Annex II of directive 2009/128/EC.

According to Annex II of the directive, the following parts must be tested:

- Power transmission parts. For electric drones, a visual inspection determining that the cables and connectors are intact is enough. For combustion engine-powered drones, it must be ensured that the power transmission parts are protected to prevent contact with any body part or clothing. Any parts that heat up must also be protected.
- The pump must be inspected with a flow meter to ensure adequate capacity, pressure generation and steady flow. If no suitable meter is available, the inspection can be carried out by measuring the pressure in the system and the volume flow rate of the nozzles. If the pressure remains steady and the equipment reaches its highest volume flow rate, the pump is in good condition.
- Drone sprayers will not necessarily feature mixing systems. Depending on the contents of the ISO 23117 standard, mixing may not be necessary in small tanks. Otherwise, mixing must be visible.
- The tank for spraying liquid must be intact. The tanks must be equipped with a pressure equalizing device, a tight cap and a gauge indicating the volume of liquid. The tank must not leak any liquid even if tilted 45 degrees when full. According to the requirements, the tank must withstand a fall.

[31] International Organization for Standardization 2014: ISO/TC 20/SC 16 Unmanned aircraft systems. https://www.iso.org/committee/5336224.html.

[32] Standarised Procedure for the Inspection of Sprayers in Europe 2018: Spise Advice. http://spise.julius-kuehn.de/index.php?menuid=34.

[33] Decree of the Ministry of Agriculture and Forestry on the requirements, inspection and risk assessment concerning spraying equipment used for plant protection products (in Finnish)https://www.finlex.fi/fi/viranomaiset/normi/2017/43363.

- If the manufacturer has installed filters in the spray or if filters will be required in the ISO 23117-1 standard, the filters must be intact, clean and compliant with the manufacturer's requirements.
- The spray nozzles must be in their original location, and the distance between the outermost nozzles must not exceed 75% of the drone's total width.
- The volume flow rate of the nozzles must be +-15% of the nominal flow rate indicated by the manufacturer or +-5% of mutually similar nozzles.

8. Spray drift in the environment

Information about spray drift is required for the risk assessment. Risk assessments typically use the spray drift results for different types of crop canopies compiled by the Julius Kühn Institute (JKI) from Germany. The results have been compiled from several studies, and the 90th percentile of these results, depicting the worst possible scenario, is used in assessments. Spray drift is measured by spraying the crops and then measuring the amount of spraying liquid deposited on the ground at different distances. This method has been standardised in ISO 22866[34]. As numerous tests have been conducted for various types of equipment, the values compiled from the results can be taken to represent the performance of the average sprayer in a specific type of crop. The crop type treated with the spraying liquid affects the results to a certain degree, as it absorbs the liquid and prevents it from spreading. The crop's ability to absorb the spraying liquid varies depending on its density, height and method of growing.

The problem in the case of drones is that no, or at least very few, measurements have been made using them. Therefore, we do not have reliable information about the spray drift of drones for different crop canopies. Measurements for risk assessments have mainly been carried out in vineyards.

According to measurements on vineyards, the spray drift from drones is comparable with that of air-assisted spraying of tree and bush crops. The spray drift results for drone sprayers have been clearly better than those for helicopter spraying. According to preliminary results, the results for drone sprayers are not quite as good as those for boom sprayers.

Spray drift must be considered in risk assessments, and overall drift should be lower than or equal to the drift of conventional methods. In risk assessments, the impact of spray drift can also be reduced by other means, for example by increasing safety distances, by reducing the overall volume of the sprayed product or by applying the safety distances determined for the spraying of tree and bush crops. The preliminary results of the Julius Kühn Institute indicate that drone sprayers are comparable with air-assisted sprayers for tree and bush crops on vineyards, if equipped with air-assisted nozzles. Spray drift is usually smaller for field crops than on vineyards. It seems appropriate to draw the conclusion that the spray drift from drones can be reduced by using the safety distances specified for the spraying of tree and bush crops.

Spray drift and the factors affecting it are part of risk assessment. It is also important to ensure that the drones used for spraying match the assumptions used in the risk assessment, such as the maximum permitted spraying height or techniques reducing spray drift.

In studies of drone sprayers conducted in wind tunnel conditions, nozzles were found to have a considerable impact on spray drift. The smaller the droplets produced by the nozzle, the larger the

[34] ISO 22866:2005 Equipment for crop protection — Methods for field measurement of spray drift https://www.iso.org/standard/35161.html.

potential spray drift. Generally speaking, the spray drift from air-assisted nozzles was the smallest in comparisons with swirl chamber nozzles or fan nozzles of the same size[35].

The research results concerning the spray drift of plant protection products are variable. Studies have been conducted on drift and deposition outside the area sprayed. In a study conducted by Herbst et al. 2020[36], the drifts from four different types of drone sprayers were relatively small and did not differ substantially from one another. The use of an air-assisted nozzle considerably reduced drift[36] and the homogeneity of spraying was also better[37]. In the study, a drone sprayer with six rotors outperformed a drone with eight rotors and a drone with a single rotor in terms of coverage and smaller drift. Different types of drone sprayers may have a notable impact on drift[38]. In the study, spray drift and deposition outside the sprayed area accounted for anywhere from a few per cent to a quarter of the spraying liquid. The largest drift was recorded for a sprayer with a spraying boom nearly as wide as the rotor. As a result, the air stream from the rotors had a stronger impact on the spraying liquid and its spread in the surroundings. In the standardisation work, the maximum distance between the outermost nozzles will probably be set at 75% of the drone's overall width, the goal being to control the impact of the rotor air stream on spray drift.

Spray drift can be reduced through risk management, for example by using adjuvants (20–65% compared to water alone[38]) or nozzles reducing spray drift. The height and density of the sprayed crop, as well as flight height also affect drift. Spray drift has also been measured in wind tunnel conditions. In a controlled environment, wind speed had the largest impact on spray drift, followed by flight height and droplet size, respectively. The rotor air stream also affected spray drift, but the spraying angle of the nozzle made no difference[39]. In the study, more than 90% of the spray drift remained within eight metres of the sprayed area, when the drone sprayer was operated at a height of five metres and the wind speed was less than 5 m/s[40].

The flight direction of drones can lead to non-homogeneous spray patterns for the crop. The difference in the behaviour of spray mist is visible to the eye, and preliminary results indicate that more of the plant protection product is sprayed across the crop when moving forward than when moving backward[41]. Non-homogeneous spraying may cause a risk of excess residues, exposure of bystanders and larger drift into the surroundings. These risks and related management measures must be considered when drawing up flight plans for drone spraying.

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[35] Wang, C., Zeng, A., He, X., Song, J., Herbst, A., & Gao, W. (2020). Spray drift characteristics test of unmanned aerial vehicle spray unit under wind tunnel conditions. International Journal of Agricultural and Biological Engineering. 13. DOI: 10.25165/j.ijabe.20201303.5716.

[36] Herbst A., Bonds J., Wang Z., Wang C., Zeng A. & He X. 2020: The influence of Unmanned Agricultural Aircraft System design on spray drift. Aspects of Applied Biology 144: 263–270, 2020 International Advances in Pesticide Application.

[37] Wang, C., Herbst, A., Zeng, A., Wongsuk, S., Qiao, B., Qi, P., Bonds, J., Overbeck, V., Yang, Y., Gao, W. & He, X. (2021). Assessment of spray deposition, drift and mass balance from unmanned aerial vehicle sprayer using an artificial vineyard. Science of the Total Environment 777 (2021) 146181. https://doi.org/10.1016/j.scitotenv.2021.146181

[38] He X., Wang W., Song J., Wang Z., Wang T., Wang S., Liu Y. & Zeng A. 2018: Drift potential of UAV with adjuvants in aerial applications. Aspects of Applied Biology 137: 9–18, 2018 International Advances in Pesticide Application.

[39] Wang, L., Chen, D., Yao Z., Ni X & Wang S. 2018: Research on the prediction model and its influencing factors of droplet deposition area in the wind tunnel environment based on UAV spraying, IFAC-PapersOnLine, Volume 51, Issue 17, s. 274–279. https://doi.org/10.1016/j.ifacol.2018.08.174.

[40] Xue X. Y., Tu K., Qin W. C., Lan Y. B., Zhang H. H. 2014: Drift and deposition of ultra-low altitude and low volume application in paddy field. Int J Agric & Biol Eng, 2014; 7(4): 23–28. DOI: 10.3965/j.ijabe.20140704.003.

[41] Giles, D.K., Billing, S & Singh W 2018: Remotely piloted aircraft for agricultural spraying: Conclusions from multiple season operations Aspects of Applied Biology 137, 2018 International Advances in Pesticide Application, s. 1–8.

The Julius Kühn Institute has studied environmental spray drift from drones, but the results have not yet been published[42]. According to preliminary research results, the drift from drone spraying is larger for vineyards than for field crops. On vineyards, the use of spray drift-reducing nozzles leads to lower drift compared with conventional tractor spraying of tree and bush crops. Regarding field crops, it is difficult for drone sprayers to beat the low drift from boom sprayers when treating the entire field.

9. Authorisation of products for drone spraying – risk assessment perspective

Risk assessments of plant protection products model the exposure to products and assess the impact of exposure to humans, various organisms and groundwater. The impact that the method of spraying has on exposure and the subsequent risks are assessed for each individual case. Owing to a lack of research, no calculation models are available for the assessment of concentrations caused by drone spraying. Therefore, the risks from drone spraying cannot yet be assessed.

Many of the research results concerning the homogeneity of spraying, spray drift, exposure to humans and biological effectiveness cannot be directly applied in risk assessment, and few scientific publications are yet available. The information provided by peer-reviewed research is a crucial element in risk assessment – risk assessment cannot be carried out without reliable research results. However, publication activities related to drones have picked up rapidly, and publications concerning agricultural drones have also become more common in recent years[43]. The main background material currently lacking for risk assessment purposes are reliable values for drift outside the sprayed area. The JKI has published these for the types of spraying equipment currently in use[24, 23].

The risk assessment tools used in the EU do not enable the assessment of health and environmental risks from drone spraying. The development of calculation models is largely dependent on the development of EU legislation. The EFSA should develop calculation models for spray drift from drone spraying so that the framework directive can enable a wider use of drone spraying in the future. At present, risk assessment would have to be carried out on a case-by-case basis, using inadequate research data and calculation models. EU-level updates to the framework directive will also include an examination of the possible future use of drone spraying.

9.1. Assessment of health risks

The assessment of health risks arising from plant protection products focuses on the different stages of product handling and spraying from the perspective of operators, workers, residents and bystanders. The risk assessment is conducted in accordance with the EFSA guidelines[44] and with the help of the EFSA calculation model, which determines exposure through the skin and airways.

Assessment of the exposure of the drone operator (user)

The user exposure is calculated during the mixing of the spraying liquid and the loading of the spray, as well as during the spraying. The calculation model includes cases and scenarios with and without personal protective equipment for the following:

[42] Herbst, A. 2021: Spray drift from drones. Presentation at the 25 February 2021 meeting of the working group for the Commission's framework directive on the sustainable use of pesticides.
[43] del Cerro, J.; Cruz Ulloa, C.; Barrientos, A.; de León Rivas, J. 2021: Unmanned Aerial Vehicles in Agriculture: A Survey. Agronomy 2021, 11, 203. https://doi.org/10.3390/agronomy11020203.
[44] EFSA 2014: Guidance on the assessment of exposure of operators, workers, residents and bystanders in risk assessment for plant protection products, EFSA Journal, Wiley Online Library. https://efsa.onlinelibrary.wiley.com/doi/abs/10.2903/j.efsa.2014.3874.

- Low field crops
- High plants such as fruit trees, vineyards
- Tractor-drawn and self-propelled sprayer
- Hand-operated spray gun
- Knapsack sprayer
- Separately for granular plant protection products

The drone operator is at the biggest risk of exposure when operating the drone sprayer, mixing the spraying liquid, loading the tank and cleaning the equipment. The operation of drone sprayers involves stages that are not present as such in traditional sprayers. The drone sprayers on the market are quite large and heavy. The equipment is lifted and moved from place to place hugging it close to the body. During the spraying operation, some of the plant protection product sticks to the surface of the drone as fine mist, and the user may potentially be exposed to it while handling and moving the equipment. During spraying, the user may have to change and charge the battery or fill up the fuel tank.

No calculation model currently exists for exposure from a hugging grip, although it may correlate to some extent with the handling of a knapsack sprayer. When operating a drone sprayer, it is important to keep in mind the atypical risk of exposure and use suitable personal protective equipment when lifting and moving the equipment. Another option is to use a suitable trailer to move the drone sprayer in the field.

The drone sprayer has a small tank for spraying liquid, which must be filled frequently. The tank is removable and can be filled while mounted on or detached from the drone. In practice, it may be difficult to fill a tank mounted on the drone, and the mouth of the tank must be large enough for this purpose. An automated filling and battery charging/changing station would be the safest option from the user's perspective. The drone sprayer should always be cleaned before moving it manually. The tank and hoses must be cleaned as instructed by the manufacturer. Washing water must be handled with care and disposed of appropriately. The tank must be equipped with a drain valve.

During actual spraying, the drone operator is not in the immediate vicinity of the drone, and exposure during spraying corresponds to that of bystanders or residents in the neighbourhood. Existing calculation models can probably be applied to some extent in the assessment of exposure during spraying, although the flight height differs from the default values used in existing calculation models. The spray mist may be carried to where the operator is controlling the drone. To reduce exposure during spraying, the operator can move upwind.

Assessment of the exposure of workers

Workers can be exposed to the crops treated with plant protection products at different stages of work. The duration of contact between the worker and the treated crop at different stages of work is considered in the assessment. The assessment uses a conservative DFR (*dislodgeable foliar residue*) value, describing the amount of plant protection product deposited on plant leaves right after spraying. The DFR research results for the product can be used to specify the estimate if the worker's exposure, using the default values, is not at a permissible level. Exposure through the airways is assessed mainly in greenhouse conditions, which is most likely not the primary place of use for drone sprayers.

The way in which the drone sprayer is used has some impact on the spraying liquid's penetration into and spread across the crop. Research indicates some variation in the homogeneity of spread in field conditions. In drone spraying conducted from above, more of the spraying liquid remains in the top layer of the crop compared with, for example, air-assisted sprayers used on vineyards, which penetrate sideways through the crop[26]. A non-homogeneous spread may affect the exposure of workers.

Assessment of the exposure of residents and bystanders
The following aspects are modelled in the assessment of residents and bystanders:

1. Skin and airway exposure to spray drift from the plant protection product during spraying
2. Airway exposure to substances evaporating from the crop
3. Exposure of skin and mouth to substances on plant surfaces
4. Skin exposure when moving among the crops

In the case of skin and airway exposure caused by spray drift, scenarios for a boom sprayer (adults and children) and air-assisted sprayer for tree and bush crops (adults) are used. In the case of exposure caused by the plant protection product evaporating from the crops during or after spraying, the focus is not on the method of spraying but instead on the product's evaporation, which is not affected by the method of spraying.

The assessment of exposure to a substance on the plant surface examines the amount of plant protection product carried to crops outside the sprayed area. The values published by the Julius Kühn Institute (JKI) for spray drift outside the sprayed area are used in modelling[24, 23]. The model can be used to calculate skin exposure and the potential oral exposure of a small child if the child puts a hand or plants contaminated by the plant protection product in their mouth. Exposure when walking among sprayed crops is calculated in the same way as a worker's exposure during short-term contact.

The JKI has as yet not published spray drift values[24, 23] for drone sprayers. Based on preliminary research results[42], the drift outside the sprayed area caused by drone spraying is smaller than that caused by air-assisted sprayers for tree and bush crops, if the drone is equipped with air-assisted nozzles that reduce spray drift. In the absence of more specific research data and scenarios, the exposure of residents and bystanders could be assessed using the model for air-assisted spraying of tree and bush crops, which is a more conservative scenario than that for drone spraying.

Practices for protecting bystanders and residents

The current decree on the aerial spraying of plant protection products addresses spraying from airplanes and helicopters. The decree specifies a minimum safety distance of 400 metres to the nearest residential area. In aviation regulations concerning drones, the safety distance to the nearest residential area in the "specific" category is 1:1 the permitted flight height. In the "open" category, the maximum flight height is 120 metres. In most cases of drone spraying, the permitted flight height would be very low. To protect bystanders and residents, it is nevertheless necessary to specify adequate safety distances to residential areas and public roads. The Finnish Safety and Chemicals Agency publishes a notification of the time of spraying on its website and the party performing drone spraying must notify bystanders and occasional passers-by of any spraying performed in the immediate vicinity of such areas.

9.2. Assessment of environmental risks

Assessments of the fate of plant protection products model the amount of plant protection products carried into the surface water, groundwater and sediment when used according to the product instructions. Spray drift is one of the contributing factors to the overall surface water drift, in addition to surface and drainage runoff. Risk assessment also includes a calculation of the exposure of arthropods and plants outside the field. The underlying principle when assessing the exposure of arthropods outside the field is that the populations must be able to recover in the following growing season. The exposure of bees and other pollinators on the field edge will also be calculated in the future. The drift values published by the Julius Kühn Institute (JKI)[24, 23] are used to calculate concentrations outside the sprayed area.

The assessment of environmental risks from plant protection products includes a modelling of the predicted environmental concentration (PEC) using FOCUS scenarios for surface water, groundwater and sediment. A separate calculator is used to determine soil concentration. The results are used to assess the impact of use on groundwater quality, birds, mammals, pollinators, arthropods, soil and aquatic organisms, as well as vegetation outside the spraying area. The spraying technique, which has a large impact on the plant protection product's drift outside the spraying area, is taken into account when modelling surface water and sediment concentrations. As the method of application does not affect soil concentration or groundwater concentration, it is not considered in the calculation models.

Drone spraying involves a greater risk of plant protection product drift than boom sprayers, for example. The assessment of environmental risks from drone spraying focuses on assessing the amount of plant protection product carried outside the sprayed area and the impacts that this has on aquatic organisms, pollinators and other arthropods, as well as the vegetation around the sprayed area.

The drift values provided by the JKI[24, 23], used in modelling, have been calculated for field crops, fruit trees, hop growing and viticulture. Separate values for the early and late growing season are provided for fruit trees and grapevines because in the late season, the larger leaf surface binds a greater amount of plant protection product, reducing drift. The values are based on research results concerning techniques typically used to apply plant protection products for these crops. The calculation model can also be used for rough estimates of the drift from aerial spraying, but it only encompasses traditional helicopter and airplane spraying.

Protection of pollinators

Many plant protection products are subject to a bee protection clause, which limits spraying to the nighttime. The use of drone sprayers at night may be problematic if visual contact cannot be maintained due to dark or foggy conditions[45].

Management of point source loading

As mentioned in connection with the assessment of health risks, the operation of drone sprayers involves stages that are not present as such in traditional sprayers. The tank for spraying liquid is small, and it must be filled or changed frequently. When filling and cleaning the tank in field conditions, special attention must be focused on the management of point source environmental loading. The safest alternative for managing point source loading is an automated filling station, with a structure that prevents point source loading while handling and filling the drone sprayer.

9.3. Residues and assessment of consumer risks

The homogeneous spread of spray mist and the risk of residues being carried to nearby crops must be considered when assessing the risk of residues. The use of drone sprayers may have an impact on the residues of plant protection products in crops if the spray mist spreads very unevenly or if excessive amounts of the product are carried to nearby fields. An uneven spread is especially problematic if the product sold is a whole plant or fruit, such as cabbage heads or apples. Individual products run the risk of exceeding the approved maximum residue limits. Residue limits may also be exceeded if larger than normal amounts of the plant protection product are carried to a nearby section. The drift values provided by the JKI[24, 23] can be used in the assessment of risks to nearby crops.

[45] Giles, D.K., Billing, S & Singh W 2018: Remotely piloted aircraft for agricultural spraying: Conclusions from multiple season operations Aspects of Applied Biology 137, 2018 International Advances in Pesticide Application, s. 1–8.

9.4. Homogeneity of spray and biological effectiveness

Homogeneity of spray

Some research has been conducted on the homogeneity of spray when using drone sprayers, and the results have ranged from good to moderate. In addition to flight height, homogeneity is influenced by the nozzle spray angle and the distance between nozzles. In drone sprayers, each nozzle sprays a different area. This differs from the method adopted in, for example, boom sprayers, which can offer improved homogeneity of spray through the partly overlapping fan pattern produced by two nozzles. If the achievement of homogeneity is based on a single nozzle, the result is slightly more sensitive to variations in, for example, height and wind speed. In Switzerland, the homogeneity of spray is inspected in connection with the approval of drone sprayers, and the measurements have shown coefficients of variation of 6–15%[46]. In drone research, it may be necessary to define the most suitable spraying width for individual drones to ensure an adequate coefficient of variation for homogeneity of spray[47]. In Finland, the maximum coefficient of variation for homogeneity allowed for boom sprayers is 10%. Compared to a knapsack sprayer, the drone sprayer is safer for the user, and neither the homogeneity of spray nor the spraying liquid's penetration into the crop differed markedly from those of knapsack sprayers, as indicated by a study conducted in the US[47].

In addition to spray drift, the homogeneity of spray of plant protection products is affected by the spraying technique and accuracy. In traditional boom sprayers, homogeneity is affected by the spraying height, placement of nozzles, condition of nozzles, line of movement, steadiness of pace and boom deformation, that is, bending. The same aspects basically apply to drone spraying. In addition, the drone is steered by making changes to its flight attitude, which must also be taken into consideration.

Drone sprayers are assumed to be used in an automatic or autonomous state, meaning that the drone independently follows the path mapped out in advance. The accuracy and appropriateness of such a flight route is better than that achieved through remote manual control.

An autonomous or automatic drone trusts its sensors, for example, to adjust its route and height. As a result, the properties of the drone as well as its sensors and actuators affect the homogeneity of spray. This makes it difficult to arrive at a synthesis of the homogeneity of spray for drones. However, some generalisations can be made. Lightweight drones have more difficulties compensating for wind, for example, which forces them to react to the impact of wind by making more aggressive changes to their flight attitude.

Other factors affecting the homogeneity of spray include the amount of product sprayed and the spraying height. Drone sprayers can adjust the amount of product sprayed or the width of spray by enabling or disabling nozzles, which affects the pattern of spray and thus the spread.

When spraying smaller amounts or when spraying at higher altitudes, the plant protection product does not spread over the crop as well as it does when using traditional sprayers. The spread is also weaker when using drones equipped with low-power pumps to spray smaller amounts.

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[46] Anken, T. & Waldburger, T. 2020: Working Quality, Drift Potential and Homologation of Spraying Drones in Switzerland. In M. Gandorfer et al. Digitalisierung für Mensch, Umwelt und Tier, Lecture Notes in Informatics (LNI), Gesellschaft für Informatik, Bonn 2020.
https://dl.gi.de/bitstream/handle/20.500.12116/31872/GIL_2020_Anken_025-030.pdf

[47] Martin, D.E., Singh, V., Latheef, M.A. & Bagavathiannan, M.V. 2020. Spray deposition on weeds (Palmer amaranth and Morningglory) from a remotely piloted aerial application system and backpack sprayer. Drones. 4(3), 59. https://doi.org/10.3390/drones4030059.

Biological effectiveness

In principle, substances have the same biological effectiveness if the same amount of an active agent is spread over the same area. However, different substances act in different ways. For example, when using a contact pesticide, a spray that penetrates the crop poorly may not reach the pest insects. Instead, weed control may be very successful. Good results of biological effectiveness were achieved at least in Switzerland. On vineyards, drone sprayers were more effective than helicopter sprayers but less effective than air-assisted sprayers.

If the impact mechanism of a plant protection product means that biological effectiveness depends on the products' spread over the crops, biological effectiveness should also be assessed, and possibly tested, for drone spraying. Any restrictions on use affecting biological effectiveness should be defined. For example, the instructions should specify the minimum amount to be sprayed per hectare or the spraying height.

In studies, the biological effectiveness of drone spraying is often compared with helicopter spraying and the spraying of tree and bush crops, for example, on vineyards. In these cases, biological effectiveness has been similar to that of the traditional spraying technique[41]. In a study published in 2014, the biological effectiveness achieved on rice plantations was roughly 70–85%[48]. In the study, the best spraying result for two different drone types was achieved at a flight speed of 3–4 m/s. The optimal flight height for good pest control results may depend on the drone sprayer model. Both drone sprayers had an optimal spraying height at which the product's spread across the crops and biological effectiveness were the best. In the study, *Chilo suppressalis*, a pest of rice, was controlled at an efficiency of 85–100%[49]. In cotton farming, the drone sprayer demonstrated 64% effectiveness against the cotton aphid and 61.4% effectiveness against the spider mite, compared with 90% and 68% respectively achieved with a boom sprayer. Despite their lower efficiency, drone sprayers are used to control cotton pests because they save resources (water, plant protection product, workload)[50].

10. Conclusions

Based on this project, the authors propose a legislative amendment to enable the use of drone sprayers for the aerial spraying of plant protection products as an exemption procedure. In practice, drone operations would mainly come into question for trial use. The aspects identified as obstacles to wider use and approval are also key areas of development in the future:

- The technology has developed rapidly without detailed compliance standards. The equipment on the market does not necessarily meet all the basic requirements for health and environmental protection applicable to plant protection sprayers. Standardisation work is found to be important, and standards for drone sprayers would facilitate risk assessment and the setting of requirements.
- Work on an inspection standard for drone sprayers has not yet been initiated, but inspections can be conducted based on existing guidelines.

[48] He, X., Liu, Y., Song, J., Zeng, A. & Zhang J. 2014: Small unmanned aircraft application techniques and their impacts for chemical control in Asian rice fields. Aspects of Applied Biology 122:33-45.
[49] Wang, C., He, X., LIU, Y., Song, J. & Zeng A. 2016: The small single- and multi-rotor unmanned aircraft vehicles chemical application techniques and control for rice fields in China. Aspects of Applied Biology 132: 73–81, International Advances in Pesticide Application.
[50] Lou Z, Xin F, Han X, Lan Y, Duan T, Fu W. 2018: Effect of Unmanned Aerial Vehicle Flight Height on Droplet Distribution, Drift and Control of Cotton Aphids and Spider Mites. Agronomy, 8(9):187. https://doi.org/10.3390/agronomy8090187.

- The environmental drift and fate – and thus the risks – of plant protection products used in drone spraying can be assessed using existing calculation models. Reliable research is required especially on the exposure of users, local residents and bystanders and on environmental drift.
- Studies on drone spraying indicate moderate or good homogeneity of spray patterns and biological effectiveness. Further research is required, and techniques must be developed to make spray patterns more homogeneous and consequently improve biological effectiveness.
- The development of EU legislation is still at an early stage, and updates to the framework directive are being discussed by the Commission, Member States and stakeholders.

APPENDICES

APPENDIX 1. Summary of the answers provided by EU Member States and Norway to the survey on drone sprayers that the Finnish Safety and Chemicals Agency conducted in spring 2020 among members of the working group for the Commission's framework directive on the sustainable use of pesticides.

Country	Drone spraying prohibited	Identified needs for use	Existing exemptions for aerial spraying	Plant protection products approved for aerial spraying	Research	Future
FR	Yes	Viticulture and banana cultivation on steep slopes	Three-year project	Permit applications for products have arrived	Three-year study underway	Any necessary legislative amendments may be made based on the research results
LU	No	Viticulture		Plant disease control in viticulture	Three-year project: drone spraying equally efficient as helicopter spraying but not as efficient as traditional methods	The rapid development of drone technology may enable wider use in the future.
PL	Yes	Forestry	Forestry	Unanswered	Some previous research	No plans to amend legislation
BE	Yes	No	No	No	No	Unanswered
HU	Yes	"Grey area" in need of regulation	Not at present	No	Unanswered	Required legislative amendment under preparation
CZ	Yes	Viticulture, orchards, vegetables in the near future	Unanswered	No	Unanswered	EU-level requirements for drone sprayers required
PT	Yes	No	No	No	Research on the remote sensing of plant pests concerning corn and other plants	Unanswered
EE	Yes	No demand at present	No	No	Unanswered	If demand arises, legislative amendments may need to be reviewed.

Country	Drone spraying prohibited	Identified needs for use	Existing exemptions for aerial spraying	Plant protection products approved for aerial spraying	Research	Future
FI	Yes	Precision farming, protection of sapling stands from elk damage	Prevention of widespread forest damage and control of plant pests posing an immediate threat to plant health	No	No trial spraying has yet been carried out using drones. Research on the identification of plant pests in agriculture and forestry.	Research is required, legislation should keep up with the rapid development of drone sprayers.
BG	Yes	No	Only possible for trial use	No	Unanswered	Unanswered
ES	Yes	High demand, no drone spraying for now	No	No	Discussion and research groups have been set up on the public side (e.g. universities) and in private companies.	Drone sprayers must be given a chance so that the goals of the framework directive can be achieved.
NO	Yes	Some inquiries		Required, but not approved	Unanswered	Local experts in plant protection sprayers are sceptical about the use of drones because they are not sufficiently accurate.
DE	Yes	Viticulture on steep slopes and prevention of forest damage	Exemption only for viticulture on steep slopes and for forest tree canopy	Required	Two studies underway	Unanswered
SI	Yes	No	No	No	Research is underway on the use of multispectral imaging and the effectiveness of plant protection product treatments in trial use and in the monitoring of crop condition.	Unanswered