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SUBSTANTIATION OF RECOMMENDATIONS FOR SAFE AERIAL APPLICATION OF PESTICIDES USED BY UNMANNED AIERIAL VEHICLES (UAVS)

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Annotation. *UAVs have many advantages over traditional aerial application methods, including greater accuracy, efficiency, availability, cost-effectiveness, and safety, as well as improved data collection and real-time monitoring. The absence of appropriate rules and regulations that would govern the use of agrodrones can jeopardize the health of people, animals and plants, and can also negatively affect environmental objects. The aim is to substantiate recommendations for the safe aerial application of pesticides using unmanned aerial vehicles (UAVs). Field research was conducted in the Vinnytsia, Kyiv, and Zhytomyr regions of Ukraine in 2019-2022 using the most common models of agricultural drones DJI Agras T16 and XAG XPlanet 2020. Statistical processing of the results was carried out using a package of licensed statistical programs IBM SPSS Statistics Base v.22, Jupyter Notebook 6.4.8 and Python 3.11. Based on studies we have conducted, we recommend maintaining the following protective zones for various objects: 500 m from settlements, animal husbandry complexes, work sites dedicated to the manual care and cultivation of agricultural crops, reservoirs and recreational areas; from fishing reservoirs, open sources of water supply, grazing places for domestic animals, objects of the nature reserve fund, areas for sowing crops that are used for food without heat treatment - 2 km; from the place of permanent residence of honey bees - 3 km. If there are apiaries near the location of aerial application, it is necessary to notify the beekeepers in advance 12 hours before the start of application, so that the beekeeper has time to take measures for the safety of the bees. The point of remote piloting of the UAV (ground control station of the drone and refueling of the sprayer tank) must be located at a distance of at least 25 m from the field border. Thus, we have developed recommendations that will simplify the use of agricultural drones, a promising technique for the agro-industrial complex, while minimizing risks for workers, the population, and the environment. The hygienic aspect of the use of UAVs needs further comprehensive and detailed study.*
Keywords: *pesticide application, UAV, hygienic recommendations, human health, environment.*

Introduction

The use of unmanned aerial vehicles (UAVs, drones) in agriculture for plant protection is becoming an increasingly popular innovative tool in countries around the world, thanks to the many advantages that this technology offers compared to traditional methods of treatment. Aerial application of pesticides is usually used for large and expansive crops, where the ground application may be impractical or ineffective and in cases where the use of ground equipment is impossible due to adverse weather conditions, terrain features, etc. [3, 9].

UAVs have many advantages over traditional aerial application methods, including greater accuracy, efficiency, availability, cost-effectiveness, and safety, as well as improved data collection and real-time monitoring. However, the use of UAVs for the plant protection products (PPP) application is a fairly new phenomenon for the agricultural sector of Ukraine and the need to regulate the legislative sphere for their effective use is very high [2, 4, 7, 8]. The absence of appropriate rules and regulations that would govern this activity can jeopardize the health of people, animals and plants, and can also negatively affect environmental objects [1, 5].

It is imperative to minimize human exposure and environmental contamination during and after crop treatment by training drone sprayer operators and using best practices such as reducing pesticide application rates and dilution water volumes, minimizing drift, digitalization and reducing the time of production processes. These actions can help protect the health of workers and the public, the environment, and preserve the health and productivity of crops for future generations.

The aim is to substantiate recommendations for the safe aerial application of pesticides using unmanned aerial vehicles (UAVs).

Materials and methods

Field research was conducted in the Vinnytsia, Kyiv, and Zhytomyr regions of Ukraine in 2019-2022 using the most common models of agricultural drones Agras T16 manufactured by DJI and XAG XPlanet 2020. Pesticides were applied from the air using UAVs on various crops at the maximum rates of pesticide consumption in accordance with instructions for their use. The agrodrone was piloted at a height between 1.5 m and 5 m, at a speed of 15-25 km/h. Meteorological parameters during research: air temperature 15-25°C, humidity - 30-80%, air speed - 1-5 m/s.

We used similar models of agricultural drones in the laboratory study. The experiment was conducted in a closed room, which made it possible to control the movement of the side wind. The air temperature in the hangar was 18-20°C, humidity - 50-60%. Brilliant Blue FCF (E133), with a

degree of purity of 95%, was used to visualize and detect the spray width and wear zone of the working solution. Air sampling was carried out using aspiration (ASA-4M electroaspirator and paper filters de-ashed "red ribbon") and sedimentation methods (paper filters de-ashed "red ribbon"). Quantitative determination of the content of active substances and Brilliant Blue FCF (E133) in the air of the working area, atmospheric air, in washings from exposed skin surfaces and gloves, and patches on workers' overalls was carried out by the method of high-performance liquid chromatography.

Calculation and risk assessment were carried out in accordance with methodical recommendations [6]. Statistical processing of the results was carried out using a package of licensed statistical programs IBM SPSS Statistics Base v.22, Jupyter Notebook 6.4.8 and Python 3.11.

The work was carried out within the framework of the Research Work Sciences "Comparative hygienic evaluation and scientific substantiation of approaches to hygienic regulations of innovative technologies applications" (State registration number: 0122U000634).

Results. Discussion

The key element of prevention of negative factors when applying pesticides from the air with the help of agro-spraying drones is the use of the most adapted pesticide formulations containing adjuvants, such as anti-evaporators, surfactants, adhesives, penetrants and others. Several factors should be considered when choosing a pesticide, such as the type of crop, the number and type of the target pest or disease, and the environmental conditions under which spraying will take place. It is important to choose a pesticide that shows optimal effectiveness against a pest or disease while being safe for the environment and human health.

In countries where pesticide application technologies using UAVs are actively being implemented, the priority group of pesticides recommended for registration for UAV application are pesticides that have already received registration for application by traditional aerial methods. Relevant regulatory bodies determine the suitability of plant protection products for use by agro-spraying drones, the need for additional rules or requirements to ensure their safe and effective use, their labeling, develop instructions for use, and determine limiting environmental factors and safety measures.

The decision to select a particular pesticide product should be based on an assessment of harm and benefit and potential risk to both humans and the environment.

For the application of pesticide formulations from airplanes, rotorcraft, and hang gliders, the buffer zone is wider than for ground processing, as it is more difficult to control the height of the pesticide spray, the speed of the vessel, and to accurately intercept the spray by an aircraft operating at high speed. But when using an agricultural drone-sprayer, the drift of droplets is lower than with traditional aerial processing (Fig. 1). This is achieved by the lower height and speed of the drone over the field and the direction of the total vector of the airflow from under the propellers of the agrodrone. A feature of the design of agro-spraying drones is the location of the nozzles under the screws, thanks to which the drops of the drug receive additional vertical acceleration with the airflow from the screws, which increases the vertical speed of droplet deposition and reduces the radius of wear (Fig. 2). However, it is also necessary to consider the size of the drops, the peculiarities of their behavior in the created air flows, and the volatility of the pesticides. The width of the buffer zone is also affected by the type of pesticide product and the presence of adjacent water bodies, as some pesticides are highly toxic to surface sources, so this should be considered when applying a pesticide.

Based on field studies we have conducted, we recommend the following protective zones for various

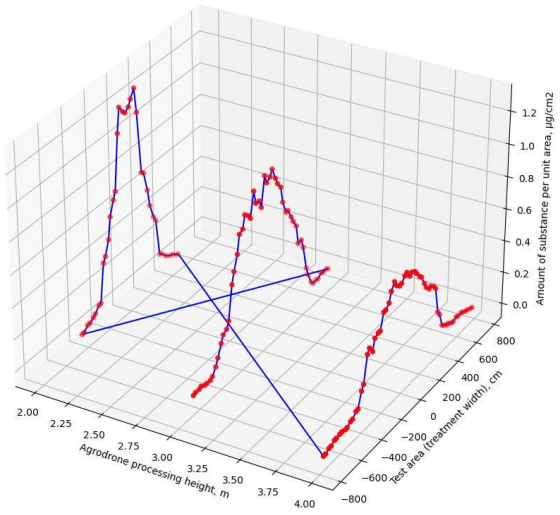

Fig. 1. Quantitative distribution of the pesticide per unit area, depending on the height of the agrodrone treatment.

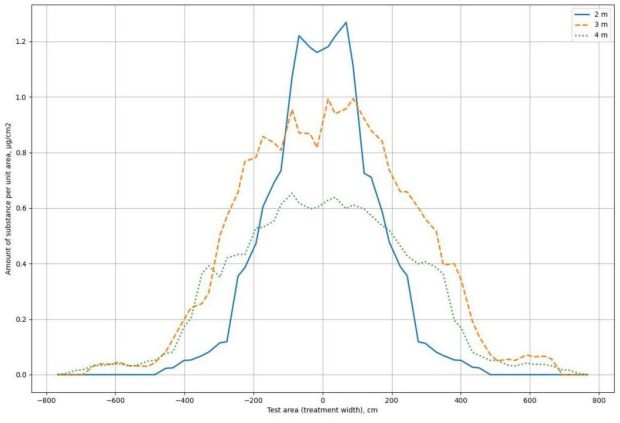

Fig. 2. Sedimentation of the pesticide working solution when applied by an agro-drone at different heights and speeds.

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objects:

- 500 m from settlements, animal husbandry complexes, work sites dedicated to the manual care and cultivation of crops, reservoirs and recreational areas;

- 2 km from fishing reservoirs, open sources of water supply, grazing places for domestic animals, objects of the nature reserve fund, areas for sowing crops that are used for food without heat treatment;

- 3 km from the place of permanent residence of honey bees. If there are apiaries near the location of application of pesticides, it is necessary to notify the beekeepers in advance 12 hours before the start of application, so that the beekeeper has time to take measures for the safety of the bees.

It is mandatory to install special safety warning signs with an indication of the final waiting period at a 300 m distance from the cultivated areas, as well as on the roads passing through these areas.

The point of remote piloting of the UAV (ground control station of the drone and refueling of the sprayer tank) must be located at a distance of at least 25 m from the site.

All work with pesticides should be carried out in the morning (before 10 am) and evening (6-10 pm) hours with minimal upward air currents and air temperature no higher than +20°C. As an exception, it is allowed to carry out processing during daytime hours in cloudy and cool weather with an air temperature below +10°C.

In advance, but not less than two or three days before the start of each chemical treatment, the administration of farms notifies the population, owners of adjacent agricultural lands and objects, about the places, terms, type of treatment and methods of pesticide application.

Before use, all technological equipment must be carefully calibrated regarding the speed of movement of agrodrones-sprayers, the speed of supply and the uniformity of the supply of the working fluid and spraying. It is recommended to choose a flight height of the UAV when spraying no more than 5 m above the top of the cultivated crop. The recommended speed of the drone during processing is 3-8 m/s. It is recommended to use injection, anti-drift nozzles to reduce pesticide drift.

Meteorological conditions have a significant impact on the safety, efficiency, and width of the formation of a buffer zone when applying pesticides from the air using a UAV:

1. It is not recommended to apply pesticides from the air at a wind speed of more than 3 m/s under most circumstances. Wind speed and direction will also affect the altitude of the UAV. If the wind speed is less than 3 m/s, a flight height of 2-4 m above the crop will ensure sufficient distribution of the working solution, but the flight height must be reduced if the wind speed exceeds 3 m/s, if the wind speed is more than 4 m/s, and it is recommended to stop working until the meteorological conditions change to the recommended ones.

Spraying must also be done with crosswinds in mind to ensure that the flight speed and application rate remain the same for both directions of flight. The drift distance of the sprayed liquid depends on the wind strength and the altitude of the UAV.

2. Spraying cannot be carried out at an air temperature of more than 25°C. For ultra-small-volume and small-volume spraying (1-10 and 10-50 l/ha, respectively), it is recommended to apply at an air temperature of up to 20°C.

3. It is recommended to apply PPP from the air with the help of agrodrones at a relative humidity of 60-70%. When applying (water-based) PPP from the air using a UAV, the high air temperature combined with low relative humidity will reduce droplet size due to evaporation, increasing the risk of drift. Atmospheric turbulence also increases with increasing temperature.

4. Absence of air convection in the surface layer of the atmosphere (temperature inversion). Temperature inversion complicates the vertical circulation of air; thus it can lead to the accumulation and long-term persistence of hazardous substances in the air.

Conclusions and prospects for further development

1. Therefore, the use of drones in the agricultural sector allows for greater accuracy, efficiency, availability, cost-effectiveness, security and improved data collection and real-time monitoring. We have developed recommendations that will simplify the use of agricultural drones, a promising technique for the agro-industrial complex while minimizing risks for workers, the population, and the environment.

The use of UAVs is very promising and will be actively and widely implemented in agricultural practice in the future, therefore the hygienic aspect of this technology needs a comprehensive and detailed study.

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ОБҐРУНТУВАННЯ РЕКОМЕНДАЦІЙ ЩОДО БЕЗПЕЧНОГО ЗАСТОСУВАННЯ ПЕСТИЦИДІВ З ПОВІТРЯ ЗА ДОПОМОГОЮ БЕЗПІЛОТНИХ ЛІТАЛЬНИХ АПАРАТІВ (БПЛА)

Борисенко А. А., Антоненко А. М., Омельчук С. Т., Бардов В. Г., Алексійчук В. Д.

Анотація. *БПЛА мають багато переваг перед традиційним авіаційним методом внесення пестицидів, зокрема більшу точність, біологічну та економічну ефективність, доступність і безпечність, а також покращений збір даних і моніторинг у реальному часі. Відсутність відповідних норм і правил, які б регулювали використання агродронів, може становити загрозу здоров'ю людей, тварин і рослин, а також негативно впливати на об'єкти довкілля. Мета - обґрунтувати рекомендації щодо безпечного внесення пестицидів з повітря за допомогою безпілотних літальних апаратів (БПЛА). Польові дослідження проводили у Вінницькій, Київській, Житомирській областях України у 2019-2022 роках з використанням найпоширеніших моделей сільськогосподарських дронів DJI Agras T16 та XAG XPlanet 2020. Статистичну обробку результатів здійснювали за допомогою пакету ліцензованих статистичних програм IBM SPSS Statistics Base v.22, Jupyter Notebook 6.4.8 і Python 3.11. На основі досліджень, які ми провели, рекомендуємо такі захисні зони для різних об'єктів: 500 м від населених пунктів, тваринницьких комплексів, місць проведення ручних робіт по догляду за сільгоспкультурами, водойм і місць відпочинку; від рибогосподарських водойм, відкритих джерел водопостачання, місць випасу домашніх тварин, об'єктів природно-заповідного фонду, площ під посіви сільськогосподарських культур, що йдуть у їжу без термічної обробки, - 2 км; від місця постійного перебування медоносних пасік - 3 км. За наявності пасік поблизу локації внесення пестицидів необхідно завчасно повідомити бджолярів за 12 годин до початку внесення, щоб бджоляр виконав певні дії для безпеки бджіл. Пункт дистанційного керування БПЛА (наземний пункт керування агродроном та заправкою бака його оприскувача) має бути розташований на відстані не менше 25 м від краю поля. Отже, розроблені нами рекомендації полегшать використання перспективних для агропромислового комплексу сільськогосподарських дронів, забезпечуючи мінімальні ризики для працівників, населення та навколишнього середовища. Використання БПЛА потребує подальшого комплексного та детального вивчення з погляду гігієни.*

Ключові слова: *внесення пестицидів, БПЛА, гігієнічні рекомендації, здоров'я людини, довкілля.*