Research on drone spraying in specialty crops in Spain

Garcerá C., Fonte A., Chueca P.*

Centro de Agroingeniería, Instituto Valenciano de Investigaciones Agrarias (IVIA), CV-315, km 10.7, 46113 Moncada (Valencia), Spain

* Corresponding author. Email: chueca_pat@gva.es

Unmanned Aerial Vehicles (UAV), specifically unmanned aerial spray systems (UASS), are foreseen to be an important technology for plant protection products (PPP) application. UASS have become a popular method of PPP application in some crops in several Asia-Pacific countries including Japan, China, and South Korea, with other countries such as India, Malaysia, Philippines, and Indonesia following suit as they approved in the last decade the uses of UAVs for these operations (Xiongkui H. et al., 2017). Additionally, activities across many countries, such as in Latin America (e.g., established regulations in Brazil), North America (e.g., commercial UASS applications in the USA, and approval of certain products for drone use in Canada), Europe (e.g., regulatory acceptance for specific applications in Germany, Switzerland, the UK, and Hungary, along with a research project involving Spanish regulatory authorities), and Africa (e.g., UASS product approval in Ghana, with growing interest from other countries) demonstrate the widespread and global interest in this technology.

Since 1983, when Yamaha Motor Co. Ltd. in Japan developed the first UAV for PPP application, the technology has significantly advanced, addressing key issues such as stability, which was initially inadequate for field use, as well as control and handling capabilities, which were even more limited. Flight path planning and automation have been other crucial areas of research for UASS, various data analysis model combinations have been proposed to identify the most efficient route for application. Additionally, improvements have been made to drone spraying and hydraulic systems, enhancing the efficiency of pest control in agricultural fields (Huang et al., 2009).

The use of the current UASS offer several advantages, including:

- Accessing crops in hard-to-reach areas, such as mountainous terrain and steep vineyards, where other vehicles may struggle.
- Minimizing ground or crop damage caused by traditional ground machinery.
- Enabling precise, localized applications thanks to their excellent maneuverability (vertical take-off and landing, low-altitude flights).
- Enhancing work capacity compared to ground treatments due to their higher operational speed.
- Reducing the PPP exposure of operators.

However, UASS also have use limitations, some related to legislation and others to technical issues. Regarding legal limitations, it is worth to mention that UAVs for PPP applications are banned in the European Union, because they are still considered aerial applications and there is a lack of knowledge of the real risk they pose to humans and the environment. On the other hand, there are restricted flight zones, which include airports, protected natural areas, and military spaces. Besides, operators are also required to hold certified training credentials, both for flying and spraying. Regarding the technical limitations, the primary challenge of UASSs is their short battery life reduces operational autonomy, leading to increased downtime during tasks. Additionally, their restricted payload capacity calls into question their efficiency to apply the high-volume rates required in many cases, making them suitable just for ultra-low volume applications, especially in tree and bush crops. Moreover, a highly precise positioning system is required to follow crop rows accurately. On the other hand, the available UAV models on the market offer limited configuration options, related to the nozzles to use, the flow rate of the pump, etc, and their effectiveness largely depends on weather conditions, particularly wind speed and direction.

Currently, multiple UASS models exist according to the type or method of UAV lift generation, that is, the number and configuration of rotors or propellers, the weight and size, and the principles of the spraying system, typically centrifugal or hydraulic. Generally, in all the UASS models the spraying system is attached to the lower part of the UAV, under the rotors. As a result, the droplet cloud generated is entirely influenced by the air currents produced by the rotors. Additionally, agricultural UAVs typically spray from top to bottom. In field crops, they cover the entire orchard surface, spraying over vegetation characterized by low height and leaf density, in contrast to tree and bush crops, where UAVs fly over tree/plant rows. This usually results in poor product deposition on the underside of the leaves and in the lower parts of the canopy (Martinez-Guanter et al. 2020; Wang et al. 2022). Although new developments are being made to improve deposition in these crops, such as the design by Qi et al. (2022), where UAVs feature nozzles that spray obliquely while flying between rows, further research is still needed.

Tree and bush crops are considered specialty crops that hold significant importance worldwide due to their economic contributions, cultural value, and environmental benefits. These crops are usually high-value, niche products that are grown for specific markets or purposes. Spain is one of the leading producers of specialty crops in Europe and globally, particularly in olives (for olive oil production), grapes (for wine), citrus fruits, and almonds.

Optimizing spray applications in specialty crops has always been a challenge. To achieve this, it is essential to consider the specific requirements of each application. As stated before, UASS are well-suited for low-volume applications, but they are unsuitable for coverage-based applications which are necessary for contact PPPs. In vertical crops, bait treatments for controlling medfly can be considered low-volume applications. These treatments aim to attract the insects to droplets deposited on the vegetation, allowing them to ingest the lure-PPP mixture and subsequently die. Therefore, such treatments do not require extensive coverage; rather, they only need to place droplets on the vegetation to act as traps. Therefore, droplets should be large (0.5-6 mm) to ensure the lure-PPP remains effective over an extended period.

On the other hand, UASS could also be an adequate technology for spraying liquid sex pheromones. Sex pheromones are the basis of the mating disruption (MD) pest management strategy. MD relies on the release of synthetic sex pheromones into the air to prevent or delay the mating of a target insect pest. It is a containment control method since it aims to keep the population under the economic damage threshold. It has been demonstrated that MD is highly effective method for many pests (Witzgall et al., 2010), such as many lepidopteran pests that affect crops of great economic interest. The synthetic pheromones are usually formulated as aerosols, which are commonly released in the orchards by means of passive dispensers (Ioriatti et al., 2011). However, recently, liquid formulations have been developed and are available on the market. In these formulations, pheromones are microencapsulated within a polymer matrix to be sprayed over the plants. These liquid formulations have proven to be as much and even slightly more effective than passive dispensers (Daane et al., 2020). They offer an advantage to farmers because they only incur costs if the pest is present during the season, unlike passive dispensers, which are placed at the start of the season without knowing whether they will be needed. However, there is a lack of knowledge on how to apply these new formulations properly, where droplets of pheromone liquid formulations that adhere to the leaves can be adsorbed, with pheromones being released from the foliage in amounts that enhance mating disruption (MD) (Suckling et al., 2007; Gavara et al., 2020), but based on the aim of this treatment, full plant coverage seems not to be necessary.

Regardless of the specific application and target pest, the efficiency of PPP applications depends on the proper setup and control of the equipment. Therefore, as with terrestrial conventional sprayers, UASS must be properly configured to maximize the effectiveness and efficacy of the operation. The operational parameters of UASS significantly influence deposition on specialty crops, including flight height, forward speed, nozzle type, rotational speed of centrifugal nozzles, nozzle flow rate, application volume rate, working pressure, nozzle position/distribution, flight pattern, and the number of sprayed passes. Additionally, some parameters affecting deposition are specific to each UAV and cannot be adjusted, such as the airflow produced by the rotors.

This work presents the approaches developed to date for optimizing bait and pheromone treatments applied with UAVs in specialty crops, conducted by the Agroengineering Center of the Valencian Institute of Agricultural Research.

The first studies focused on determining the proper setting of the UAV to fulfil the requirements of bait treatments. For that, the effect of different factors: type of nozzle, nozzle position in the drone, and advance speed, on the deposition on the canopy and the ground spray losses were studied. The results showed that conventional hollow cone nozzles were not adequate for bait treatments due to the low impact size, which increases the potential drift losses. On the other hand, it was observed that higher coverage and impact density above the canopy were achieved with flat-fan air induction nozzles compared to multi-hole fertilizer nozzles, and greater impact density was observed at 12 km/h than at 24 km/h on average. However, at 24 km/h, the number of impacts was sufficient to meet the bait treatment requirements, with double work-capacity. The flat-fan nozzle produced smaller impact sizes and a more uniform distribution of impact sizes compared to the fertilizer nozzle. Nevertheless, the impact sizes generated by the flat-fan nozzle met the requirements for bait treatments, while the impacts from the fertilizer nozzle were too large and may have caused run-off.

Next experiences were aimed to evaluate the spray distribution and the pest control efficacy of bait treatments applied with UASS in citrus and persimmon crops to control *Ceratitis capitata* and in olive crop to control *Bactrocera olae*.

In citrus and persimmon orchards the bait treatment sprayed with UAV were compared with the terrestrial reference treatment, which consists of producing a jet directed towards the middle part of the canopy, using a single nozzle without diffuser and without air. In the reference treatment, the forward speed was around 5-7 km/h and the pressure was 1.1 bar, and only the south-east side of all rows of trees was sprayed. The total spray volume applied was 7-10 L/ha. The UAV worked at a flight speed of 24 km/h and at a nozzle pressure of 1 bar, and only two air-induced nozzles located on the same side of the UAV were used. The flight height was 1.5-2 m above the citrus canopies and the spraying was done over all the rows. The spray volume applied was 7.58 L/ha. In both treatments, the PPP used was ‘Spintor Cebo’ at a dose of 1 L/ha.

The results showed that the UAV distributed the droplets mainly above the canopy, while the terrestrial sprayer using a single nozzle deposited a continuous line 3.19 cm-wide at 1.6 m from the ground. Penetration into the canopy was low with both application methods. The losses to the ground were very low in both cases. Regarding the efficacy, the terrestrial treatment showed values of medfly per day and trap higher than the UAV treatment. The percentage of fruit attacked by *C. capitata* prior to harvesting was similar without significant differences in both treatments.

In olive orchard, the bait treatment applied with UAV using ‘Spintor cebo’ and a spray volume of 9 L/ha was compared with the terrestrial reference treatment, that consisted of a full coverage treatment applied with airblast sprayer using acetamiprid as active ingredient, at a volume rate of 450 L/ha. As expected, the distribution of the canopy was very different between treatments, due to the differences in the spray volume and type of application. The spray distribution with UAV was like the one got in citrus and persimmon crops, and the spray distribution of the reference treatment was the commonly obtained for airblast sprayers in globular trees. Regarding the efficacy, the values of number of flies per trap and day was lower for the UAV treatment than for the reference one.

Therefore, bait treatments on citrus, persimmon and olive crops with UAVs got better or at least similar efficacy than the terrestrial reference treatments. This together to the reduction of the application time and low PPP exposure of operators and environment, makes this treatment a sustainable and effective alternative to the terrestrial one.

In parallel, other experiences to assess the effectiveness and efficiency of the application with UAV and terrestrial sprayers of a new liquid pheromone to control *Lobesia botrana* in vineyards were conducted. In this case, due to the lack of knowledge on the deposition requirements for this application, UAV was set up in a similar way to the bait treatment configuration, and the terrestrial sprayer, which was an airblaster, was set up to apply a band spray on the leaf wall, with one hollow nozzle and without air, applying 60 L/ha. The differences in the pheromone distribution across the vegetation between both treatments, evidenced by the higher deposition of clustered and smaller droplets in the lateral canopy in the case of the terrestrial sprayer, and the higher deposition on the top of the canopy with larger droplets in the case of the UAV, were a direct consequence of the distinct spray technologies and its set-up. Pheromone concentration in the air was assessed as a measure of the potential efficacy against *Lobesia botrana* of each treatment. In this regard, it was found that the concentration on the day when applications were performed reached values above 10 ng/m^3 with both spray technologies, with significantly higher values with the UAV (14.01±0.48 ng/m^3) than with the terrestrial sprayer (11.29±0.82 ng/m^3). However, one week after the applications, concentration dropped to 4.42±0.36 ng/m^3 in the UAV-treated orchard, while the drop was lower for the terrestrial sprayer-treated orchard (6.81±0.85 ng/m^3), although the difference was not statistically significant. On the second week and the third week the trend was similar. Therefore, UAV could be a potential equipment for spray liquid pheromones, but more research on the deposition requirements for this application is needed to optimize these treatments.

In conclusion, it has been demonstrated that the application of bait treatments and pheromone sprays with UAV is possible, but it is important to set up the system adequately to improve its efficiency.

References

Daane, K.M.; Yokota, G.Y.; Walton, V.M.; Hogg, B.N.; Cooper, M.L.; Bentley, W.J.; Millar, J.G. 2020. Development of a Mating Disruption Program for a Mealybug, Planococcus ficus, in Vineyards. Insects, 11: 635. https://doi.org/10.3390/insects11090635

Gavara, A.; Vacas, S.; Navarro, I.; Primo, J.; Navarro-Llopis, V. 2020. Airborne Pheromone Quantification in Treated Vineyards with Different Mating Disruption Dispensers against Lobesia botrana. Insects, 11: 289. https://doi.org/10.3390/insects11050289

Huang Y., Hoffmann WC., Lan Y., Wu W., Fritz BK. 2009. Development of a spray system for an unmanned aerial vehicle platform. Appl Eng Agric. 25:803 - 9. https://doi.org/ 10.13031/2013.29229.

Ioriatti C.; Anfora, G.; Tasin, M.; De Cristofaro, A.; Witzgall, P.; Lucchi, A. 2011. Chemical ecology and management of Lobesia botrana (Lepidoptera: Tortricidae). J Econ Entomol., 104(4): 1125-1137. https://doi.org/10.1603/EC10443

Martinez-Guanter J., Agüera P., Agüera J., Pérez-Ruiz M. 2020. Spray and economics assessment of a UAV-based ultra-low-volume application in olive and citrus orchards. Precision Agric, 21: 226–243. https://doi.org/10.1007/s11119-019-09665-7

Qi P., He X., Liu Y., Ma Y., Wu Z., Wang J. 2022. Design and test of target-oriented profile modeling of unmanned aerial vehicle spraying. Int J Agric & Biol Eng, 15(3): 85–91. DOI: 10.25165/j.ijabe.20221503.6753

Suckling, D. M., Daly, J. M., Chen, X., & Karg, G. (2007). Field electroantennogram and trap assessments of aerosol pheromone dispensers for disrupting mating in Epiphyas postvittana. Pest Management Science, formerly Pesticide Science, 63, 202-209.

Wang C., Liu Y., Zhang Z., Han L., Li Y., Zhang H., Wongsuk S., Li Y., Wu X., He X. 2022. Spray performance evaluation of a six-rotor unmanned aerial vehicle sprayer for pesticide application using an orchard operation mode in apple orchards. Pest Management Science, 78(6): 2449-2466. https://doi.org/10.1002/ps.6875

Witzgall P., Kirsch P., Cork A. 2010. Sex Pheromones and Their Impact on Pest Management. J Chem Ecol 36:80–100. DOI 10.1007/s10886-009-9737-y

Xiongkui H., Bonds J., Herbst A., Langenakens J. 2017. Recent development of unmanned aerial vehicle for plant protection in East Asia. Int J Agric & Biol Eng 10 – 3. (https://www.ijabe.org/index.php/ijabe/article/view/3248/pdf).