RECENT J. (2023), 71:249-255
https://doi.org/10.31926/RECENT.2023.71.249

Engineering and Management of the Precision Treatments Spraying System Implementation on Horticultural Crops

Ioana Mădălina PETRE
Transilvania University of Brasov, Romania, ioana.petre@unitbv.ro
Sebastian POP
Transilvania University of Brasov, Romania, pop.sebastian@unitbv.ro
Mircea BOȘCOIANU
Transilvania University of Brasov, Romania, mircea.boscoianu@unitbv.ro

Abstract
The paper presents an analysis of the precision treatments spraying system implementation on horticultural crops. The aim of the paper is to present the typical architecture and the functionality of a spray treatment application system, mounted on a mini-multicopter UAV. The laboratory model of a miniUAV-RW aerial platform adapted for precision transport with high payload rate was presented. Methods of applying the currently existing phytosanitary treatments were identified and innovative solutions were identified for the topic addressed. The proposed precision treatments spraying system improves the quality of spraying, necessary to cover to a greater extent the surfaces and crops. This application is very interesting and actual for a lot of end-users in the actual context of precision agriculture and horticulture constraints.

Keywords
mini-unmanned aerial vehicles (miniUAV), precision treatments, spraying system, horticulture, crops

1. Introduction

The application of unmanned aerial vehicles (UAVs) provides new viable capabilities and tools for crop protection [1], offering an alternative to ground machines and manual knapsacks, especially for complex terrain and tall trees [2]. The new capabilities offered by microelectronics, materials, sensors has leveraged the classic missions and applications offering also a better efficiency of the missions and applications.

An UAV specialized in applying treatments to agricultural crops is an innovative and effective solution for optimizing the plant care process. It can be used in agriculture for various purposes, such as fertilizing, spraying pesticides or herbicides, monitoring crop health, and even harvesting in some cases. In the case of agricultural and horticultural applications is still difficult to scale the aerial system because of the typical payload for these missions, but in the literature we can see a growth interest for miniaturization.

It will need a lot of research to integrate miniUAVs, a novel kind of plant protection, into current commercial crop protection systems. The degree of environmental contamination and the efficiency of disease and pest management are examples of evaluation indicators. For shaped ground or aerial application equipment, the surrounding meteorology, wind speed, and temperature listed on the pesticide instructions are typically appropriate [3].

Many factors may influence the coverage, droplet size, and drift potential of UAV spraying, such as the selection of appropriate meteorological conditions, flight altitude, flight speed, nozzle types, and droplets size [3 … 6].

Improving spray quality is necessary to increase crop droplet coverage. The specialists are optimistic on the future integration of these capabilities. Again, in the future the focus will be on the miniaturization of the aerial systems, especially in rotary wing architectures.

Using a drone to apply treatments in agriculture can reduce costs, increase efficiency and minimize environmental impact, while providing more accurate monitoring and smarter management of agricultural resources.

The aim of the paper is to present the typical architecture and the functionality of a spray treatment application system, mounted on a mini-multicopter UAV (the so- called miniUAV-RW). This application is very interesting and actual for a lot of end-users in the actual context of precision agriculture and horticulture constraints.

2. State of the Art in the Field of Precision Treatments Spraying System

The spray application method on crops involves the use of specialized equipment to apply pesticides, herbicides, fertilizers, or other substances to agricultural fields. The methods typically utilizes sprayers, which can be either handheld or mounted on vehicles, to disperse the desired substances in the form of fine droplets or mist onto the crops.

Application methods include ground application (via implement or attachment sprayers) and aerial application (via manned agricultural aircraft).

Different types of sprayers, such as boom sprayers, air-assisted sprayers, or aerial sprayers, may be used depending on the crop type, field size, and specific requirements. Factors like weather conditions, wind speed, and nozzle selection also play a crucial role in achieving accurate and efficient spray application.

Both UAV and ground applications have their own advantages and considerations when it comes to crop spraying.

The mini UAV applications, also known as aerial spraying, involve the use of drones equipped with sprayers to apply substances to crops from the air. This method offers several benefits, such as:

1. Accessibility: UAVs can access areas that may be difficult or impossible for ground-based equipment to reach, such as steep slopes or densely planted fields.
2. Efficiency: Aerial spraying can cover large areas quickly, potentially reducing the time and labour required for application.
3. Precision: UAVs can be equipped with advanced technologies like GPS and imaging systems, allowing for precise targeting and application of substances, minimizing waste and optimizing effectiveness.

On the other hand, the conventional ground applications involve using sprayers mounted on vehicles or handheld equipment to apply substances directly to crops from the ground. Some advantages of ground applications include:

1. Flexibility: Ground-based sprayers can navigate through various terrains and adapt to different crop types and field conditions.
2. Control: Operators have more direct control over the application process, allowing for adjustments based on real-time observations and conditions.
3. Cost-effectiveness: Ground-based equipment may be more affordable and accessible compared to UAVs/ miniUAVs, especially for the case of smaller-scale operations.

The selection between UAV and the conventional ground applications depends on factors such as the size and layout of the field, crop type, terrain, budget, and regulatory considerations. It is important to assess these factors and consult with agricultural experts or professionals to determine the most suitable application method for specific circumstances. There still exists some risks associated to the more innovative methods, namely UAVs/ miniUAVs related to the initial costs, maintenance costs, but the technological progress is in its favour.

Gibbs et al. [7] conducted some experiments to compare UAV application to the ground (implement) application methods. The four trials included: UAV without boom, UAV with boom, implement (boom) without pulse technology, and implement (boom) with pulse technology. Compared to the implement methods, coverage was higher and more localized in the middle swath of the field for the UAV methods.

Xiao et al. [8] compared the droplet deposition and control efficiency of unmanned aerial vehicle (UAV) and electric air-pressure knapsack (EAP) sprayers on a processing pepper field. The UAV/ miniUAV sprayer had a poor droplet coverage rate, droplet density, and deposition uniformity, but displayed the best deposition (1.01 $\mu g/cm^2$, which was 98%more than the EAP sprayer).

Wang Z. et al. [9] reported that the use of UAVs for the purpose of pesticide application can result in droplet drift at a certain altitude, which may cause harm to non-target organisms. One way to reduce drift is by increasing droplet size. However, applicators also consider optimal pest control efficacy when using small droplets, because fine droplets, despite being more susceptible to drift, possess a greater ability to penetrate and adequately cover the crop canopy [9, 10]. In this case the literature focused on the miniaturization possibilities is still in an early stage of practical research.

Biglia et al. [11] analysed the performance of the UAV-spray system was compared to that of a conventional ground-based spray application machine, which is an axial fan sprayer coupled with a tractor. The results indicated that the flight mode deeply affects spray application efficiency. Compared to the broadcast spray modes, the band spray mode was able to increase the average canopy deposition from 0.052 to 0.161 $\mu L \cdot cm^{-2}$ (+ 309 %) and reduce the average ground losses from 0.544 to 0.246 $\mu L \cdot cm^{-2}$ (−54 %). The conventional airblast sprayer, operated at a low spray application rate, showed higher canopy coverage and lower ground losses in comparison to the best UAV-spray system configuration.

As some researchers stated, the droplet sizes of UAVs are approximately 270–350 µm, smaller than the droplet size of ground-based machinery, which is approximately 300–1000 µm [12, 13]. There are smaller droplets (less than 200 µm in diameter) that have a higher risk of drift [14, 15].

In addition to particle size, flight altitude and speed, ambient wind speed, temperature and humidity, and rotor wind fields influence spray quality and drift [3, 16, 17].

If a higher spray penetration and effectiveness for the target area is needed, for environments like orchards, tall trees, and vast canopies it is difficult to find the right application method.

During spray applications on bush and/or tree crops with airblast sprayers, only a fraction of the total applied product is deposited on the intended target, especially when the sprayers are not adjusted to match it [18]. So, a relevant amount of the spray mixture can represent undesirable off-target losses.

3. Installation of the Treatment Spraying System on Multicopter

The design of the laboratory model of the aerial platform for precision treatments spraying took into account that it should be able to carry a payload of 10 l, in a specially adapted tank. Starting from this requirement, the following activities were carried out for the design and physical realization of the model as follows:

- Choice of motors and related propellers;
- Determination of the geometric configuration of the multicopter. Assembling the laboratory model;
- Choice of tank, pump and spray system. Assembly of the laboratory model;
- Choosing the autopilot and integrating it into the air system.

Based on the estimate of calculated masses, it resulted that the motorization must have a traction of at least 5 kg/motor, sufficient traction for a maximum takeoff weight of 15 kg of the planned drone.

In this sense, the X8 XRotor engines with the following specifications were chosen: maximum thrust 15 kg/motor at 46 V AMSL, recommended battery 12S LiPo, recommended weight / engine 5-7 kg/engine, engine weight 1150 g, IPX6 standard, operating range -20 °C to +65 °C.

The propellers used are 30-inch folding composite propellers with a pitch of 9°.

The geometric configuration of the multicopter took in consideration the chosen motors and propelles, so, it was decided to build a multicopter in X configuration of the quadrocopter type.

Using the eCalc software, the technical characteristics of the entire UAV were simulated and the speed zone in which the multicopter has the best efficiency was obtained.

The data are presented in the graph in Figure 1 and the best range is marked with green.

The precision treatments spraying system is composed of a tank, solution distribution pump, tubes and fittings and spray nozzles.

The tank (Figure 2a) is constructed of materials resistant to the chemicals used to prevent corrosion or other reactions that could affect its integrity. The capacity of the tank can vary depending on the specific needs of the agricultural application or the capacity of the transport drone, from a few litres to tens or even hundreds of litres. For safe handling, the tank should be provided with a tight closure system and safety mechanisms to prevent spills or other incidents. In this case, a 10 l tank was chosen, made of plastic material, equipped with two holes (filling and draining), thus being very easy to integrate the treatment distribution pump.

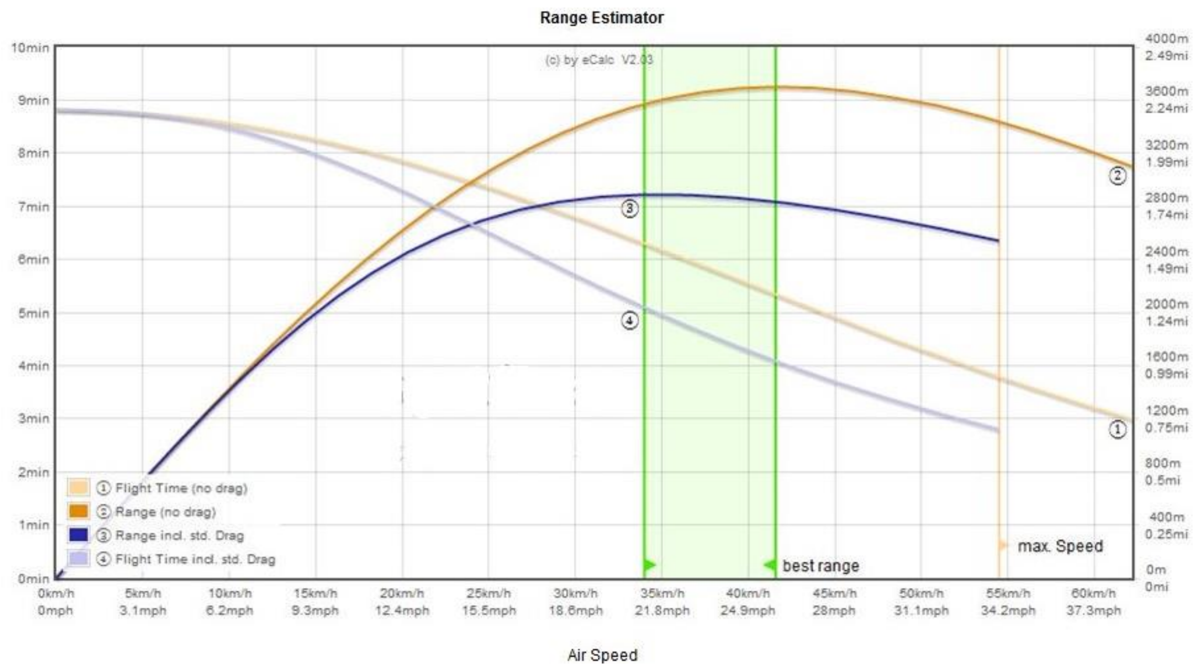

Fig. 1. Flight speed estimation in the case of mini UAV-RWs

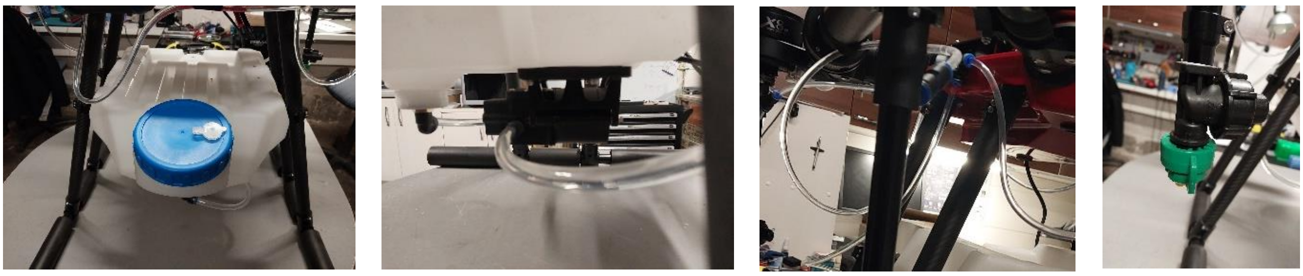
a. tank | b. solution distribution pump | c. tubes and fittings | d. spray nozzles

Fig. 2. Spraying system

Pumps can be of various types, such as piston pumps, diaphragm pumps, or rotor pumps, depending on the specific needs of the agricultural application. The pump should provide the ability to adjust the dose of the substance delivered to suit different application needs. Since the chemicals used in agriculture can be corrosive, the pump must be constructed of corrosion-resistant materials. At the same time, it must be able to be ordered by means of the commands transmitted by the drone's automatic pilot. For the correct operation of the developed system, a COMBO-PUMP-5L pump with the following specifications was chosen: working voltage 44-60.9 V (12-14 S); maximum power 150 W; working pressure 0.35 MPa; current 2.5 A; IPX6 standard; maximum flow rate 5 l/min; weight 388 g; size 123×76×52 mm. It is presented in Figure 2b.

The tubes are usually made of materials resistant to the chemicals used, to prevent corrosion or other chemical reactions, the most commonly used material being plastic. The diameter of the pipes can vary depending on the type of substance, the pressure required and the amount of liquid to be transported. Pipes must be equipped with filter systems to prevent particles or impurities from entering the spray nozzles.

Piping must have strong, leak-proof connectors and couplings to prevent leaks and facilitate assembly and disassembly of the system for maintenance or replacement. It is also important to have a clear labelling system for pipes, indicating the type of substance that flows through them, to avoid confusion and ensure safe handling.

Flexible hoses with an inner diameter of 6 mm were used for the proposed solution. Their coupling to the distribution system was made with self-sealing quick couplings, as seen in Figure 2c.

As for the spray nozzles, there are various types, such as cone nozzles, flat jet nozzles, uniform dispersion nozzles, etc., and the choice depends on the type of substance applied and the requirements of the crop. The nozzles can be adjusted to produce larger or smaller droplets depending on the coverage required and the type of treatment being applied. Ensuring a uniform distribution of substances is essential to avoid over-dosing or under-dosing in different areas of the crop. Nozzles should be adjustable to allow adaptation to various wind conditions or specific crop requirements, as well as the vortex generated by the drone's propeller. Figure 2d presents the spray nozzles used for the treatment spraying system.

The scheme of the spraying system can be seen in Figure 3.

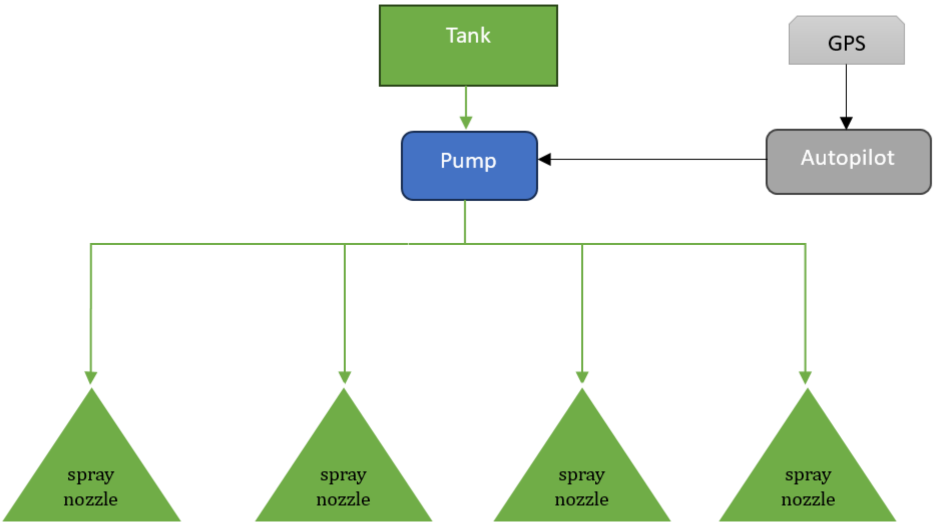

Figure 3. Spraying system scheme

Choosing an autopilot for a multicopter drone is crucial to the overall performance and functionality of the drone. Pixhawk is a popular and widely used autopilot in the drone community due to its advanced features and flexibility. The Pixhawk Orange Cube autopilot with Here3 GPS was chosen and implemented. The Orange Cube is an autopilot developed by the ArduPilot community and is part of the Pixhawk autopilot family. It features the processing power of an ARM Cortex-M7 processor and has a wide range of sensors, such as accelerometer, gyroscope, magnetometer and barometer, contributing to the stabilization and precise navigation of the drone. With multiple connectivity ports, Cube Orange enables the connection and control of various devices and sensors. Support for global navigation systems such as GPS, GLONASS and Galileo ensures accurate positioning. Built-in modules for wireless communication, such as Bluetooth and Wi-Fi, make it easy to configure and monitor the drone remotely.

Interfacing the spray pump with the autopilot within an agricultural drone brings several benefits, contributing to the efficiency and precision of the treatment application process. Here are some key reasons why it is important to have such an interface:

1. Precise dose control

The interface of the spray pump and autopilot allows for precise control of the dose of the substance released according to the specific needs of the crop and the treated area. The autopilot can automatically adjust pump flow in real time, ensuring treatments are applied according to field requirements.

2. Adaptability to the elevation differences of the land

The autopilot can receive data from sensors that measure terrain elevation or from external sources (DEM maps), crop condition or other relevant factors. This information allows the autopilot to automatically adjust the dose of substance according to the specific needs of different areas of the terrain and at the same time its flight can follow the terrain profile.

3. Optimization of Flight Routes

The autopilot can plan and execute optimized flight paths to ensure full and even crop coverage, minimizing overlap or bare areas. The interface with the spray pump allows precise synchronization between the movements of the drone and the activation of the pump according to the position and needs of the respective area.

4. Economy of Resources

By interfacing with the autopilot, the spray pump can be intelligently controlled to avoid over-dosing or under-dosing, helping to save resources and substances used.

5. Energy Efficiency

The autopilot can optimize flight paths and pump activation times based on specific treatment requirements. This can lead to more efficient use of energy and greater autonomy of the drone.

6. Real-Time Data and Post-Mission Analysis

The autopilot can provide real-time data on mission status, including the amount of substance released and terrain coverage. This data is useful for performance monitoring and post-mission analysis, contributing to the continuous improvement of the treatment application process.

After the physical installation of the autopilot on board the drone, the following calibration steps were performed:

- Physical connection of the autopilot to the radio receiver, the GPS module, the current sensor and the power supply;
- Connecting to the computer: it is done with a USB cable through the Mission Planner or QGroundControl application;
- Firmware setting: the firmware specific to the chosen multicopter configuration is installed;
- Calibration of inertial sensors: it is done by accessing the sensor calibration section from the menu of one of the two softwares;
- Compass calibration: performed by rotations around all axes, following software instructions;
- Calibration of the propulsion system: it is necessary to synchronize the response of the Electronic Speed Controllers and verify the correct direction of rotation of the propellers.

All of these operations were accomplished by tracking how the control command components are linked and interfaced correctly.

4. Conclusions

In this article it was presented a precision treatments spraying system mounted on a multicopter UAV (miniUAV-RW). The proposed system, is a balanced one with an aerial subsystem capable to support a high payload rate. The aim is to improve the quality of spraying, necessary to cover to a greater extent the surfaces and crops, and in this case the payload rate is essential. The technological progress of microelectronics, materials, communication, navigation is relevant now and we can be optimistic in this adaptation of miniUAV-RW for precision agriculture and horticulture. All these contribute synergistically and harmoniously to the progress of the system as a whole for the proposed applications and tasks.

The architectural system presented offers scalable capabilities, an essential fact in the technological transfer of the near future.

Acknowledgement

This work was supported by a grant of Ministry of Research, Innovation and Digitization, CCCDI - UEFISCDI, project number PN-III-P2-2.1-PED-2021-3678, within PNCDI III.

References

1. Li X., Giles D.K., Niederholzer F.J., Andaloro J.T., Lang E.B., Watson L.J. (2021): *Evaluation of an unmanned aerial vehicle as a new method of pesticide application for almond crop protection*. Pest Management Science, eISSN 1526-4998, Vol. 77, is. 1, pp. 527-537, https://doi.org/10.1002/ps.6052
2. Giles D. (2016): *Use of remotely piloted aircraft for pesticide applications: issues and outlook.* Outlooks on Pest Management, eISSN 1743-1034, Vol. 27, is. 5, pp. 213-216, https://doi.org/10.1564/v27_oct_05
3. Wang J., Ma C., Chen P., Yao W., Yan Y., Zeng T., Chen S., Lan Y. (2023): *Evaluation of aerial spraying application of multi-rotor unmanned aerial vehicle for Areca catechu protection.* Frontiers in plant science, eISSN 1664-462X, doi: 10.3389/fpls.2023.1093912
4. Huang Y., Hoffmann W.C., Lan Y., Wu W., Fritz B.K. (2019): *Development of a spray system for an unmanned aerial vehicle platform*. Applied Engineering in Agriculture, eISSN 1943-7838, Vol. 25, is. 6, pp. 803-809, doi:

10.13031/2013.29229
5. Teske M.E., Thistle H.W., Fritz B.K. (2019): *Modeling aerially applied sprays: an update to AGDISP model development*. Transactions of the ASABE, eISSN 2151-0040, Vol. 62, is. 2, pp. 343-354, doi: 10.13031/trans.13129
6. Wang J., Lan Y.B., Yao W.X., Chen P., Lin J., Yan Y. (2019): *Effects of working height of single-rotor unmanned aerial vehicle on drift and droplets deposition distribution of areca tree*. Transactions of the Chinese Society of Agricultural Machinery, ISSN 1000-1298, Vol. 50, is. 7, pp. 109-119, doi: 10.6041/j.issn.1000-1298.2019.07.011
7. Gibbs J., Peters T.M., Heck L.P. (2021): *Comparison of Droplet Size, Coverage, and Drift Potential from UAV Application Methods and Ground Application Methods on Row Crops*. Transactions of the ASABE, eISSN 2151-0040, Vol. 64, is. 3, pp. 819-828, https://doi.org/10.13031/trans.14121
8. Xiao Q., Du R., Yang L., Han X., Zhao S., Zhang G., Fu W., Wang G., Lan Y. (2020): *Comparison of Droplet Deposition Control Efficacy on Phytophthora Capsica and Aphids in the Processing Pepper Field of the Unmanned Aerial Vehicle and Knapsack Sprayer*. Agronomy, eISSN 2073-4395, Vol. 10, is. 2, p. 215, https://doi.org/10.3390/agronomy10020215
9. Wang Z., Hussain M., Yin J., Yuan M., Mo Y., Quan M., Duan L., Tan W. (2023): *Analysis of Droplet Deposition and Maize (Zea mays L.)Growth Control: Application of Ethephon by Small Unmanned Aerial Vehicle and Electric Knapsack Sprayer*. Field Crops Research, ISSN 0378-4290, Vol. 292, is. 3, DOI:10.1016/j.fcr.2023.108822
10. da Cunha J.P.A.R., Marques R.S., Alves G.S. (2016): *Deposição da calda na cultura da soja em função de diferentes pressões de trabalhoe pontas de pulverização* (*Spray deposition on soybean crop as a function of different service pressures and spray nozzles*). Revista Ceres, eISSN 2177-3491, Vol. 63, is. 6, pp. 761-768, https://doi.org/10.1590/0034-737X201663060003 (in Portuguese)
11. Biglia A., Grella M., Bloise N., Comba L., Mozzanini E., Sopegno A., Pittarello M., Dicembrini E., Eloi Alcatrão L., Guglieri G., Balsari P., Ricauda Aimonino D., Gay P. (2022): *UAV-spray application in vineyards: Flight modes and spray system adjustment effects on canopy deposit, coverage, and off-target losses*. Science of The Total Environment, eISSN 1879-1026, Vol. 845, art. 157292, https://doi.org/10.1016/j.scitotenv.2022.157292
12. Yallappa D., Veerangouda M., Maski D., Palled V., Bheemanna M. (2017): *Development and evaluation of drone-mounted sprayer for pesticide applications to crops.* Proceedings of 2017 IEEE Global Humanitarian Technology Conference (GHTC), DOI:10.1109/GHTC.2017.8239330
13. Ling W., Du C., Ze Y., Xindong N., Shumao W. (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, eISSN 2405-8963, Vol. 51, is. 17, pp. 274-279, https://doi.org/10.1016/j.ifacol.2018.08.174
14. Chen P., Douzals J.P., Lan Y., Cotteux E., Delpuech X., Pouxvie, G., et al. (2022): *Characteristics of unmanned aerial spraying systems and related spray drift: A review*. Frontiers in Plant Science, eISSN 1664-462X, Vol. 13, https://doi.org/10.3389/fpls.2022.870956
15. Klein R.N., Schulze L., Ogg C.L., Vieira B.C. (2019): *Spray Drift of Pesticides*. NebGuide, Nebraska Extension, https://extensionpublications.unl.edu/assets/pdf/g1773.pdf
16. Wang J., Liang Q., Zeng T., Zhang X., Fu W., Lan Y. (2022): *Drift potential characteristics of a flat fan nozzle: A numerical and experimental study*. Applied Sciences, eISSN 2076-3417, Vol. 12, is. 12, https://doi.org/10.3390/app12126092
17. Zhan Y., Chen P., Xu W., Chen S., Han Y., Lan Y., Wang G. (2022): *Influence of the downwash airflow distribution characteristics of a plant protection UAV on spray deposit distribution*. Biosystems Engineering, eISSN 1537-5129, Vol. 216, pp. 32-45, https://doi.org/10.1016/j.biosystemseng.2022.01.016
18. Grella M., Marucco P., Zwertvaegher I., Gioelli F., Bozzer C., et al. (2022): *The effect of fan setting, air-conveyor orientation and nozzle configuration on airblast sprayer efficiency: insights relevant to trellised vineyards*. Crop Protection, eISSN 1873-6904, Vol. 155, art. 105921, https://doi.org/10.1016/j.cropro.2022.105921