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HYGIENIC JUSTIFICATION OF THE CALCULATING MODEL OF PESTICIDES INDICATORS FOR SAFE APPLICATION BY USING UNMANNED AIRCRAFT VEHICLES

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Introduction. The need for substantiating regulations for the safe application of pesticides using unmanned aerial vehicles intersects several important areas and has a significant impact on agriculture, environmental protection, and public health.

The aim of the research was to provide a hygienic rationale for a model calculating indicators for the safe application of pesticides using unmanned aerial vehicles.

Materials and methods of the research. The experimental part was conducted in an enclosed facility (hangar) with an air temperature of 19 °C, humidity of 50 %, and airflow speed of 0.1 m/s. The most common models of agricultural drones, DJI Agras T16 and XAG XPlanet 2020, were used. Statistical analysis of the obtained results was performed using IBM SPSS Statistics Base v.23, Python 3.11 with libraries such as Numpy, Pandas, Matplotlib, and Scipy, as well as the web-based computational environment Jupyter Notebook 6.4.8.

Results. The coverage density of the treated surface (95 % of the total amount of applied substance) ranged from 0.42 μg/cm^2 to 0.87 μg/cm^2. The coverage density of the treated surface (100 % of the total amount of applied substance) ranged from 0.26 μg/cm^2 to 0.57 μg/cm^2. The effective coverage width (the width of the area where 95 % of the applied substance reached) at a spraying height of 2 m was (564.0 ± 0.58) cm, at 3 m was (850.0 ± 1.0) cm, and at 4 m was (903.0 ± 1.53) cm. The research results indicate a significant difference in the application density depending on the spraying height by the agricultural drone, which amounts to (0.745 ± 0.030) μg/cm^2 at a height of 2 m, (0.669 ± 0.008) μg/cm^2 at 3 m, and (0.439 ± 0.005) μg/cm^2 at 4 m.

Conclusions. The obtained equation of linear regression can be used to model correlation relationships between the dependent variable and one or several independent variables. Such a model will help understand the relationship between surface coverage density and spraying height, determine the optimal spraying height for achieving the desired coverage density, establish the optimal parameters for surface treatment, and minimize unintended losses of plant protection chemicals.

Key words: pesticides, UAV, calculation model, coverage density, application regulations

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Introduction

The necessity to justify regulations for the safe application of pesticides using unmanned aerial vehicles (UAVs) lies at the intersection of several critical domains and significantly impacts agriculture, environmental conservation, and public health [1, 2]. The use of agricultural drones for crop protection through the application of pesticides can provide high precision and effectiveness, reduce labor and resource costs associated with traditional pesticide application methods. UAVs can perform this task faster and more efficiently [3, 4]. Moreover, it can also reduce health risks for workers, as they will not be directly exposed to pesticides during application, and mitigate negative environmental impacts through the use of ultra-low-volume and low-volume pesticide spraying techniques [5, 6].

Decreasing crop losses, improving the quality of agricultural produce, timely response to disease and pest outbreaks, and targeted application of plant protection chemicals are indisputable advantages of using agricultural drones. However, all the mentioned benefits of drones can be negated or even become risk factors if they are not used correctly [7]. The need for legislative regulation of their usage is highly crucial, as the absence of appropriate rules and norms governing this activity could pose a threat to human, animal, and plant health, as well as have adverse effects on environmental objects [8, 9].

The development of UAV technology and its application in agriculture holds significant innovative potential. It fosters the emergence of new methods and approaches to farming, which can open new horizons for economic growth of the country and its population as a whole.

Therefore, the aim of our work was to provide a hygienic justification for the model of calculating indicators for the safe application of pesticides using unmanned aerial vehicles.

Materials and methods of the research

The research was conducted by the staff of the Institute of Hygiene and Ecology at the O. O. Bogomolets National Medical University in collaboration with Polissia National University, LLC «Green House 2025», and LLC «Syngenta». The experimental part took place in an enclosed facility (hangar) with an air temperature of 19 °C, humidity of 50 %, and airflow velocity of 0.1 m/s. The most common models of agricultural drones, namely DJI Agras T16 and XAG XPlanet 2020, were used. Aerial pesticide application was simulated under various conditions at a normal flow rate of 8.0 liters per hectare. The drone's flying height was varied at 2 meters (Experiment No. 1), 3 meters (Experiment No. 2), and 4 meters (Experiment No. 3), with a speed of 20 km/h.

For the visualization and detection of the spray width and droplet drift, Brilliant Blue FCF (E133, purity degree 95 %) was used. A method for determining its content in filter paper was developed using high-performance liquid chromatography [10]. In each experiment, three rows of filter paper, each 17.6 meters long and 0.5 meters wide, were placed in the field. Each row was divided into 35 sectors (S35). Each sector was further divided into 30 parts (S30). Subsequently, in laboratory conditions, the concentrations of E133 were determined in the sections and sectors (Figure 1).

The obtained results were subjected to statistical analysis using IBM SPSS Statistics Base v.23, Python 3.11 with the Numpy, Pandas, Matplotlib, and Scipy libraries, as well as the web-interactive computational environment Jupyter Notebook 6.4.8. For the calculations, samples were taken

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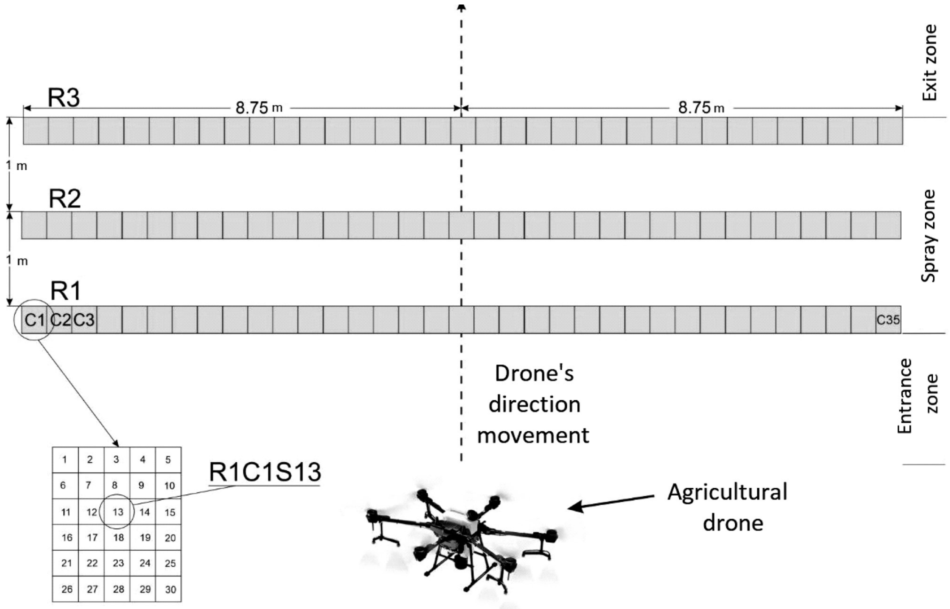

Figure 1. Scheme of pesticide spraying by an agricultural drone and the drift zone during the research

from three experimental strips of filter paper, each measuring 60 cm in width and 17.6 meters in length, with three repetitions.

Results of the research and their discussion

The obtained results of E133 concentration determination using high-performance liquid chromatography in laboratory revealed that the density of coverage on the treated surface (95 % of the total applied substance) varied between 0.42 μg/cm^2 and 0.87 μg/cm^2. The coverage density on the treated surface (100 % of the total applied substance) ranged from 0.26 μg/cm^2 to 0.57 μg/cm^2. Additionally, the effective treatment width (the coverage width containing 95 % of the applied substance) at a spraying height of 2 m was (564.0 ± 0.58) cm, at 3 m was (850.0 ±1.0) cm, and at 4 m was (903.0 ± 1.53) cm (Figure 2–4).

No significant difference in the amount of substance deposited on the filter paper during spraying of the working solution by the agricultural drone from heights of 2 and 4 meters was detected ($p = 0.221$ according to the Student's t-test). However, a significant difference in this indicator was found when the agricultural drone operated at heights of 2 and 3 meters and 3 and 4 meters ($p < 0.001$ and < 0.001, respectively). Similar results were observed when comparing the assessment of discrepancies in the «95 % of the total applied substance» indicator at heights of 2 and 4, 2 and 3, and 3 and 4 meters ($p = 0.218$, < 0.001, and < 0.001, respectively).

Concentrations of the substance (coverage density) were calculated based on the amount of applied substance (95 % and 100 % of the specified quantity) and the area of the filter paper on which the substance was determined. A significant difference in coverage density was found between heights of 2 and 4 meters and 3 and 4 meters, both for 95 % and 100 % of the applied substance ($p = 0.008$ and 0.007, and $p < 0.001$ and < 0.001, respectively). However, no significant difference in the aforementioned indicator was observed at heights of 2 and 3 meters ($p = 0.136$).

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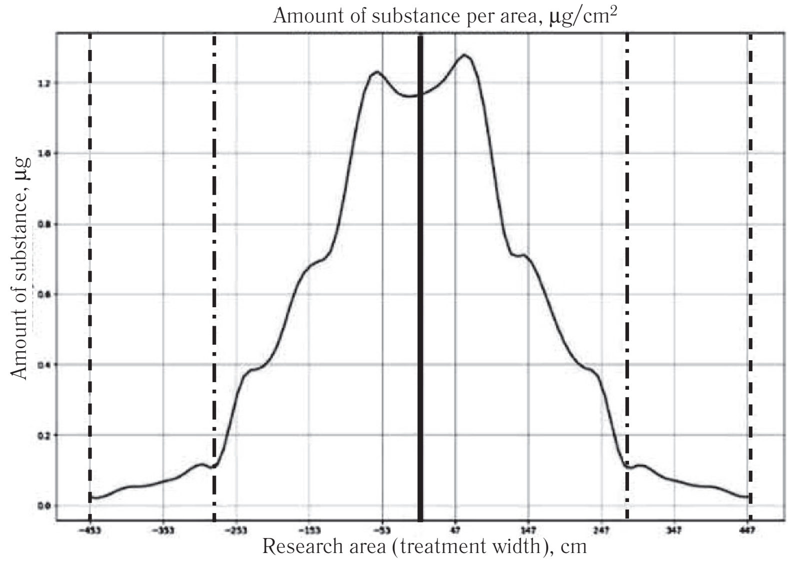


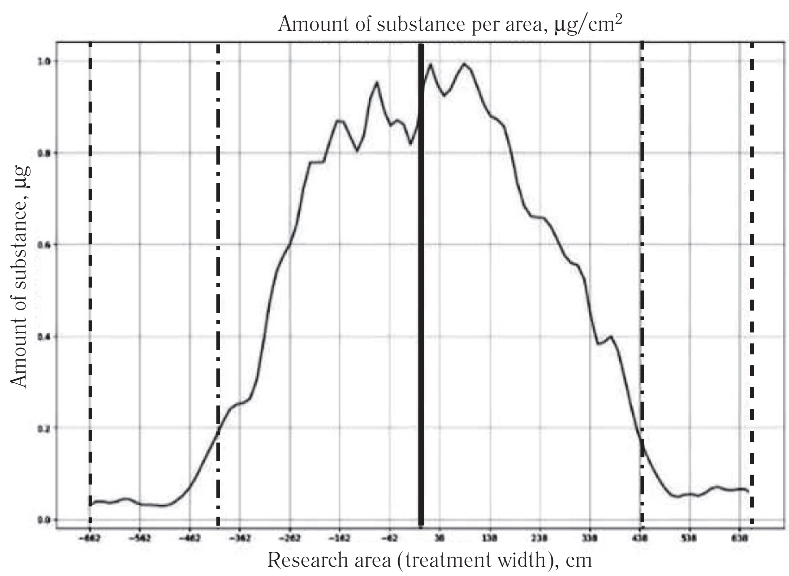
Research data: Experiment №1
Total area under the curve: 442.3
Area under the curve at zone between the 2.5% and 97.5% of coverage range: 411.2
Distance range, cm: -277.1 – 244.9
Coverage width, cm: 522.0
Substance's concentration on coverage width, mcg/cm²: 0.788
Total width, cm: 907.4
Substance's concentration on full width, mcg/cm²: 0.487
Dash-dotted lines = 95% coverage width
Dotted lines = 100% coverage width
Solid line = The central line of the drone's flight
Value line = Trendline

Figure 2. Surface Coverage Density (Experiment No.1 results, n = 3)

The width of 95 % coverage significantly differed between the mean values obtained in Experiments No. 1–3 ($p < 0.001$). Numeric values of the obtained results are presented in Table.

The results of the study indicate a significant difference in coverage density depending on the height of application by the agricultural drone, which is as follows: at a height of 2 meters – (0.745 ± 0.03) μg/cm², at 3 meters – (0.669 ± 0.008) μg/cm², and at 4 meters – (0.439 ± 0.005) μg/cm².

The obtained results underwent statistical analysis to identify correlation relationships; and it was found that there is a direct correlation – $R < 0$ at a significance level of $p < 0.001$ (coefficient of linear correlation $R = -0.943$; coefficient of determination = 0.889). This allowed constructing a linear



Research data: Experiment №2
Total area under the curve: 598.6
Area under the curve at zone between the 2.5% and 97.5% of coverage range: 565.6
Distance range, cm: -401.5 – 433.7
Coverage width, cm: 835.2
Substance's concentration on coverage width, mcg/cm²: 0.677
Total width, cm: 1325.0
Substance's concentration on full width, mcg/cm²: 0.452
Dash-dotted lines = 95% coverage width
Dotted lines = 100% coverage width
Solid line = The central line of the drone's flight
Value line = Trendline

Figure 3. Surface Coverage Density (Experiment No. 2 results, n = 3)

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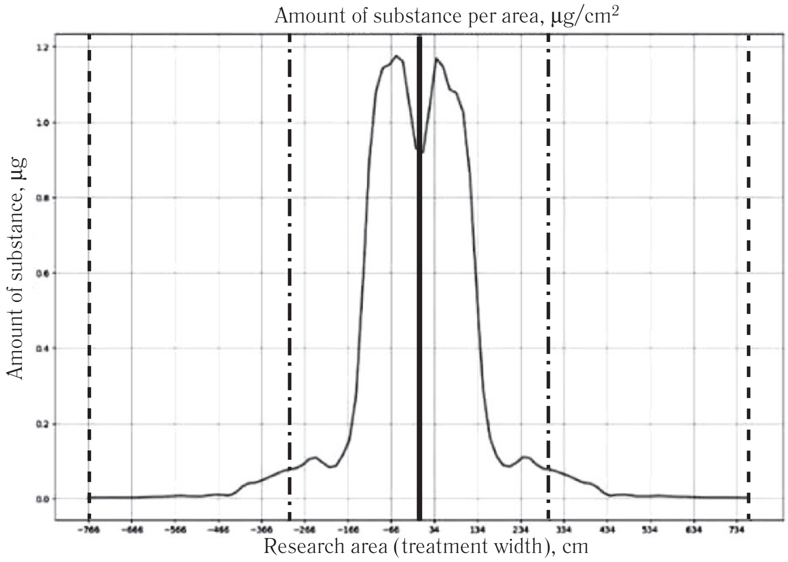

Research data: Experiment №3
Total area under the curve: 334.7
Area under the curve at zone between the 2.5% and 97.5% of coverage range: 315.6
Distance range, cm: -297.1 – 277.1
Coverage width, cm: 574.2
Substance's concentration on coverage width. mcg/cm²: 0.550
Total width, cm: 1533.8
Substance's concentration on full width, mcg/cm²: 0.218
Dash-dotted lines = 95% coverage width
Dotted lines = 100% coverage width
Solid line = The central line of the drone's flight
Value line = Trendline

Figure 4. Surface Coverage Density (Experiment No. 3 results, n = 3)

regression equation for the relationship between surface coverage density and application height.

$DC = -0.1528 \cdot H + 1.076$, where

DC – Density of Coverage, μg/cm²;

H – Height, meters;

-0.1528 – coefficient of variation for the Height parameter;

1.076 – constant value.

This linear regression equation. developed based on the obtained results of laboratory research on the surface concentration (density) of the applied substance and field experiments on the height of the agricultural drone's flight, serves as a data analysis tool that can help understand

Table

Surface coverage density of the substance E133 during the operation of the agricultural drone at different heights

Parameter	Values of the indicator in each experiment (95 % confidence interval)		
	Experiment No. 1	Experiment No. 2	Experiment No. 3
Total amount of the determined substance, μg	442.30 ± 16.83 (369.8–514.7)	598.70 ± 6.16 (572.2–625.2)	417.10 ± 4.17 (399.1–435.1)
Amount of the substance at 95 % coverage, μg	420.10 ± 15.95 (351.5–488.7)	568.60 ± 5.82 (543.5–593.6)	396.20 ± 3.98 (379.0–413.3)
Width of the area covered by 95 % of the applied substance, cm	564.0 ± 0.58 (561.5–566.5)	850.0 ± 1.0 (845.7–854.3)	903.0 ± 1.53 (896.4–909.6)
Width of the area on which the substance was determined, cm	906.0	1324.0	1532.0
Concentration of the substance in the coverage zone (95 % of the total applied substance), μg/cm²	0.745 ± 0.030 (0.62–0.87)	0.669 ± 0.008 (0.64–0.70)	0.439 ± 0.005 (0.42–0.46)
Concentration of the substance in the coverage zone (100 % of the total applied substance), μg/cm²	0.488 ± 0.020 (0.41–0.57)	0.452 ± 0.005 (0.43–0.47)	0.272 ± 0.003 (0.26–0.28)

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and predict the relationships between variables and make optimal parameter choices in research or production processes. It enables the prediction of the amount of substance that can reach a certain distance from the central trajectory of the agricultural drone's flight (allowing the calculation of the treatment coverage area and the safety protection zone).

Conclusion

The obtained linear regression equation can be used to model correlation relationships between the dependent variable and one or several independent variables. Such a model will help understand the relationship between the surface coverage density and the flight height; it will identify the flight heights that lead to optimal coverage density and establish the optimal surface treatment parameters, while minimizing non-target losses of plant protection chemicals.

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