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Impact of the Parameters of Spraying with a Small Unmanned Aerial Vehicle on the Distribution of Liquid on Young Cherry Trees

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Abstract: Research was carried out concerning spraying young cherry trees with a multirotor drone: a hexacopter. The aim of the study was to evaluate the impact of the following: the nozzle type, the air stream from the drone rotors and the size of spacing between the trees on the distribution of the liquid sprayed in the crown of the trees being sprayed. Experimental trials were conducted on a laboratory test stand. Air-injector spray nozzles: single and a twin flat were used interchangeably to spray the liquid. The travelling speed of the drone was 1.0 m·s^{-1}. A drone of 106.7 N weight was accepted in the study. The value of the spray liquid deposited and the uniformity of the liquid deposition in the crowns of the trees as well as the transverse distribution of the liquid under the nozzles were evaluated. It was found that the air stream from the drone rotors increased the distribution of the liquid on the trees sprayed, mainly at the middle and lower levels of the crown. A higher deposition value of the liquid was sprayed from the twin flat nozzle than from the single flat nozzle. There was no significant effect of the difference in the distance between the trees, of 0.5 and 1.0 m, on the liquid distribution. Under the influence of the air jet, the uniformity of the liquid distribution in the crowns of the trees also improved.

Keywords: multicopter; UAV; drone; tree spraying; nozzle; spray deposition; thrust force

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1. Introduction

Plant pest management systems are being enriched using a new technical solution: unmanned aerial vehicles (UAVs) commonly known as drones. Drones can be used in precision agriculture for the purpose of inspection raids to assess plant health and development, as well as fertilizer requirements [1–3]. Inspection raids in agriculture can also be performed to assess the condition of agricultural land and to classify it [4].

Attempts are being made to use UAVs for aerial application of pesticides to plants, as well as in other field work [5–8]. Most crop spraying drone designs are rotorcraft designs using thrust from the air stream produced by propellers rotating at high speed to maintain their position in the air and to move over objects. These may be single-rotor drones (helicopters) or multirotors (multicopters) [9–14]. Electric motors are mostly used to drive the rotors; however, internal combustion engines are also used.

The advantage of using multirotor drones in plant protection against pests is their ability to stop over the object being sprayed or to move over plantations with variable and adjustable speed. Since the drone operator may remain outside the area where the treatment is carried out by drones, unlike typical sprayers (tractor, backpack and handheld), those carrying out the treatment are protected from the harmful effects of chemicals sprayed on their health. Controlling the flight of unmanned aerial vehicles can be performed in various ways, the simplest being to use a radio transmitter controlled by the operator. Drones are equipped with sensors and control systems that enable them to maintain their flight at an operator-set altitude over objects. UAVs can therefore perform precise raids over crops and trees located at variable terrain heights [15]. They can also spray plants of different sizes from a pre-planned raid height [16]. Advanced drone control systems allow tasks to be performed based on a map of the field and the flight path previously entered into the drone control system or designated objects, which may be individual trees selected for treatment. This advantage of drones, which offers the possibility to perform spot treatments on selected objects may be more advanced as the locations for spraying can also be selected by an autonomous object identification system, which can be mounted on the drone. This solution would allow drones to autonomously search for pests on crops or plants infested with them in the future and to perform spraying immediately once these have been identified [2,15,17–19]. Currently, produced multirotor drones for spraying, especially with an electric drive, compared to self-propelled or tractor sprayers, have small capacity liquid tanks (from 5 to 30 L) and short times for air raids, from a few to tens of minutes, for instance [20,21]. Because the spray liquid tank needs to be topped up frequently during treatment and the batteries need to be changed, so the use of drones for crop protection can be most useful in small crop areas, at varying altitudes of the terrain, where a large part of the crop protection work is conducted with small tractor or backpack sprayers. The use of multirotor drones there may help to reduce the cost of pesticide application and to reduce environmental pollution, as well as to increase the biological efficiency of pesticide application [22,23].

In addition to spraying crops grown in fields, attempts are also being made to use rotorcraft drones to spray trees in parks and forests as well as on fruit trees in orchards [24–27]. Trees require an appropriate pest management technique to ensure that pesticides are applied evenly throughout the crown and to reduce any drift and pesticide losses. The traditional methods of spraying trees in orchards, using tractor-mounted or self-propelled sprayers and backpack sprayers involves applying pesticides to the crown from the side of the trees, from technological routes located between tree rows. These sprayers are most frequently equipped with blowers that generate an auxiliary air stream, which pushes a cloud of drops between the branches. When trees are sprayed using these sprayers, it is only part of the spray volume that is deposited in the crown of the tree. The remainder of the spray settles on the ground beneath the trees, or it is carried away from the application site by the wind [28,29]. The quality of the spray application on trees is influenced by many factors such as the characteristics of the tree crown, the properly selected spray dose, the nozzle type, the distance between the spray nozzle and the tree surface being sprayed, the operating speed, the flow rate of fluid from the nozzle, the droplet size, the speed and direction of the air flow and the air capacity of the fan [30–34]. In addition, there are many characteristics of the tree crown that strongly influence the total spray deposition on the tree. These are the tree crown shape, the tree crown size, the density and the volume, the total leaf area and the leaf wall porosity [35]. In typical orchard sprayers with auxiliary air flow, the most commonly used standard nozzles are centrifugal nozzles (cone nozzles). These nozzles operate at high liquid pressures of up to 20 bar. Another solution to reduce fluid losses are drift reducing venturi air nozzles, which do not require high fluid pressures [28,36]. Spray nozzles should always be directed towards the tree because, as research has shown, regardless of the sprayer type and tree architecture, this always has a positive effect on the amount of the fluid deposited on the tree [29,36].

Spraying fruit trees with drones operating from the air above the trees differs from the typical "from the side" spraying of trees using sprayers. This means that the distribution of the liquid in the tree crown may be influenced by even more factors than when spraying using sprayers. For example, droplet deposition density can be influenced by the shape of the upper part of the tree crown. It has been found that crowns with inverted triangle or "Y" shapes have significantly better spray coverage than conical crowns with the triangular blade pointing upwards, which are typical for trees. It has also been found that as the LAI, i.e., the leaf area index increases, droplet deposition density decreases, so proper shaping and pruning of the tree crown is recommended to improve the deposition of pesticides sprayed from a drone [37,38]. For a specific individual tree crown structure and the spraying drone type, the optimal application spray height and spray rate should be selected [38]. For this purpose, using inspection drones, it will be possible, before the application of pesticides, to assess the crown and to individually select the tree species in the plantation for treatment. On this basis, the dose of spraying liquid can be planned, which can then be applied, also using drones [39,40].

Drones, also similar to ground-based sprayers, require the appropriate equipment, e.g., the use of different spray nozzles. Nozzles in multirotor drones are mounted either on arms where rotors with propellers are located, or on a boom positioned transversely in the flight direction. They are always located below the rotors. The need to conserve electricity, which is used both to drive the drone rotors and to pump the spraying liquid, is an incentive to use the lowest liquid pressure possible in the nozzles. Therefore, the selection of appropriate nozzles for drone treatment against pest is very important. In drones, in contrast to orchard sprayers, the intensity of the air stream coming from drone rotors and operating in plants cannot be freely adjusted, as it depends mainly on the weight of the drone and the ceiling of its flight. Moreover, the air stream generated by rotating drone propellers may cause distortion of the liquid stream produced by the spray nozzles and a drift of droplets in directions that are frequently very different from the direction of their fall caused only by hydrodynamic and gravitational forces [41]. The air flowing out of the drone rotors surrounds the droplet stream produced by the nozzle causing a decrease in the spray angle and, as a result, this may cause a narrowing of the spray width [42]. The shape of the droplet stream resulting from air action may also depend on the design and size of the drone frame, especially the number and power of the rotors and their arrangement in relation to the nozzles [43]. The different design of tree spraying drones compared to orchard sprayers and the different methods and conditions of performing tree spraying treatments require research into the application of this equipment for tree protection. The settling quality of the drone spray applied to trees may also be influenced by other factors that are not anticipated for sprayers, which can only be identified through experimentation.

The aim of the study was an attempt to assess the influence on the quality of spray distribution in the tree crown of such factors as: the type of nozzle mounted on the multirotor drone, the air flow originating from the drone rotors and the spacing of trees in the row. It was decided to test the effect on spray distribution in the crown of trees sprayed from above by using a twin-flow nozzle compared with a single-flow nozzle. The aim of the study also included an attempt to clarify the causes of possible variations in spray distribution.

2. Materials and Methods

2.1. Test Stand

The large number of factors influencing the effectiveness of the aerial spraying of trees by drones has led to attempts to simplify test sites in order to eliminate at least some of these factors. For example: artificial trees and artificial grapevines [44,45] have been used for research instead of natural ones. In order to observe phenomena that are difficult to evaluate during field tests, tests are carried out in laboratory spaces [42,44,46]. Tree spraying studies using a multirotor drone were conducted under laboratory conditions in a closed hall with gravity ventilation. This prevented undesirable weather conditions such as wind blowing, ambient temperature and humidity from affecting the results [47]. In addition, the drone was attached to a trolley moving on a track placed above the trees being sprayed. The track was stably supported at opposite ends by brackets. This ensured that the position of the drone in relation to the sprayed objects was repeatable in both lateral and vertical (height above the objects) directions. This solution also ensured the repeatability of the drone speed. In this way, it was possible to reduce the number of the repetitions of measurements. Placing the drone on a trolley being dragged along a track also enabled comparative tests to be carried out between spraying the trees without an air stream from the rotating rotors, which could be switched off, and with rotors rotating.

The trolley with the drone was dragged using a rope attached to the trolley, which was rewound on a drum attached to the axis of the electric motor [16,47]. A hexacopter drone was used in the study, equipped with DJI 4114, kV 400 electric motors and 15 × 5.2 inches propellers. The drone was equipped with a UT-372 optical tachometer to measure propeller revolutions. The spraying system consisted of a single nozzle, a pressurized liquid supply line from a small wheelbarrow sprayer and a laboratory manometer. The liquid pressure before entering the nozzle was 0.2 MPa.

Air-ejector nozzles were chosen for the study to avoid excessive wind drift when spraying trees in the field with a drone. Two types of air-ejector nozzles produced by Lechler were used interchangeably: the IDK 120-02 is a compact air-injector flat spray nozzle with single opening, the IDKT 120-02 is a compact air-injector twin flat spray nozzle where streams of drops are deviated by 60° from each other. Both streams, in relation to the symmetry axis of the nozzle, are deviated at an angle of 30°. The intensity of outflow of the liquid at the pressure of 0.2 MPa from both nozzles is 0.65 L·min^{-1}. At this pressure, both nozzles produce drops classified as very coarse drops [48]. Both types of these nozzles have so far been used on field sprayers.

As the drone was resting on the trolley and was attached to it, the total weight of the drone, including the full tank, equal to approximately 11 kg, was accepted for the tests to generate thrust. This was similar to the specifications of a light commercial drone used for crop spraying, for example M4E [49]. Based on a previously determined mathematical formula describing the impact of propeller speed on the thrust of this drone, published in [50], the rotor speed of 6000.0 rpm was calculated and accepted for the study. This rotational speed of the propellers allowed the generation of a thrust force equal to 106.7 N (10.9 kg). In order to compare the impact of the air stream from the rotating propellers on the distribution of the liquid deposited in the tree crowns with the results of spraying performed with the same drone without any air stream, a second rotor speed of 0.0 rpm was established for the study.

The tests were conducted on three two-year-old cherry trees (*Prunus cerasus*) of the "Meteor" cultivar, 1.2 m high, grown on the F12/1 rootstock. The pots with the trees were placed under the drone in such a precise manner that during the drone's movement, the symmetry axes of the tree crowns and the symmetry axes of the droplet sampler distribution were located exactly in the symmetry axis of the nozzle. The liquid spray nozzle was mounted on the drone at a distance of 0.15 m below the propellers, exactly in the symmetry axis of the rotor. The rotor with the nozzle and the position of the drone in relation to the trees to be sprayed is shown in Figure 1.

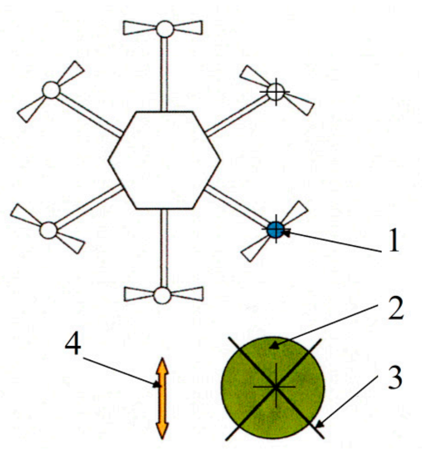


Figure 1. The drone position in relation to the trees being sprayed: 1—drone rotor, under which the nozzle is mounted, 2—samplers, 3—position of the trees in relation to the nozzle, 4—direction of the drone moving.

The height of the nozzle position above the trees when spraying them was 1.0 m. In spite of the fact that, on average, cherry trees are planted in orchards at intervals of 2 to 3 m, for this experiment, intervals of 0.5 and 1.0 m were adopted to test how excessive tree density might affect the distribution of spray in the crown and under the crown.

2.2. Liquid Distribution Measurements

The evaluation of the volume of liquid deposited on the trees can be carried out by means of samplers located at different levels of the trees. Samplers can be used on leaves collected from sprayed trees, paper or plastic samplers attached to leaves or on branches and also on stands integrated into trees [26,27,36–38,51],. The evaluation of droplet distribution in the tree crown was carried out by capturing liquid droplets reaching the different levels of the tree crown. The space in and around the crown was divided into three levels constrained by the surface. The upper level was marked with number "1". This was the level of the tree top and it marked the entry area of the droplet stream into the crown. The level marked with number "2" included the area in the middle of the crown, and the level marked with number "3" was located just below the crown and it marked the area where the droplet stream left the crown. To prepare the measuring stand and to determine the levels in the trees, bamboo poles were used, which were placed in the pots and to which the trees had previously been attached. Three sets of metal rods crossed at right angles were attached to the poles. The rods for level "1" were attached to the pole by the first tree in the row below the drone. The rods for level "2" were attached to the pole by the third tree in the row, and the rods for level "3" were also attached to the pole by the first tree. The stand prepared for measuring the distribution of the droplet stream in the trees is presented in Figure 2. The distance between level one "1" and level two "2" was the same as between level "2" and "3"; it was equal to 0.30 m. On each rod, there were two locations marked to place the samplers used to collect the droplets. Self-adhesive polyethylene labels measuring 20 × 40 mm were used as samplers. The samplers were glued to the rods at distances of 0.10 and 0.20 m from the center of the pole, which the rods were attached to on the prepared stand. This method of measuring the penetration of liquids into the tree crown proved to be the most stable of all presented methods in terms of constancy of the location of the measurement points and samplers and was non-destructive for tree foliage.

Figure 2. View of cherry trees with rod levels marked.

Performing the tests in the laboratory allowed the use of an intense dye in the spray liquid in order to be able to determine the amount of liquid deposited on the samplers. The spray liquid used for the study was a 0.5% solution of nigrosine mixed with water. While spraying the trees, the drone moved to one side and back again. Once the liquid had dried, the samplers were removed from the rods. Each measurement in the experiment was repeated three times. The droplet tracks, containing nigrosine, were then washed, always in the same volume of distilled water. The solution was analysed using a photocolorimeter. Based on the concentration of the solution, the mass of the dye deposited with the spray liquid on the sampler was calculated. Since the concentration of the dye in the spray liquid was constant, the mass determined of the dye on the samplers was taken as a measure of the liquid deposited on the samplers.

In order to determine the impact of the tree crowns on the deposition values of the liquid on the samplers placed in the tree crowns, tests were performed on the deposition of the liquid sprayed from the drone on the same rods with the samplers but without the presence of the trees. The rods were placed, as in the case with the trees, on vertical poles, at the same distances from each other, and at the same heights. The tests were performed with the same spray parameters as with the samplers in the trees.

Taking into account the fact that the number of levels with placed samplers and the distance between sampler levels are subjective values and can be selected differently, it was decided to introduce an objective factor allowing us to unambiguously determine the influence of the air stream, coming from a multicopter, on the distribution of sprayed liquid in the tree crown. For this, the uniformity coefficient of liquid deposition CV was determined [11,26,27,37,38]. The CV coefficient was calculated from the results of the mass of dye deposited on the samplers. It was calculated separately for each measurement according to the formula described in Equation (1).

$$\mathrm{CV} = \frac{1}{v_{sr}} \sqrt{\frac{\sum (v_i - v_{sr})^2}{3}} \tag{1}$$

where CV is the uniformity coefficient of liquid deposition on tree levels, v_{sr} is the average mass of dye on samplers on all levels, v_i is the mass of dye at i-th level.

2.3. Evaluation of Liquid Stream

In order to clarify the reasons for the changes in the amount of the liquid deposited on the samplers and the changes in the uniformity of the liquid distribution in the crowns of the trees, under the influence of the air stream coming from the rotations of the drone propellers at 6000.0 rpm, tests were performed focused on the transverse distribution of the droplet stream under the spray nozzles used in this study. The use of a groove table as a method for measuring the transverse distribution of the droplet stream was abandoned because, in earlier studies, a strong air stream caused the liquid to move uncontrollably along the groove walls and to merge with each other when flowing off the table. This caused erroneous results of droplet stream distribution measurements [41]. For the measurement of the transverse distribution, a 2.0 m long metal rod was used as a patternator, on which the same samplers as those used for the measurement of the liquid distribution in the tree crown were stuck in marked places at a distance of 0.10 m. The rod was positioned transverse to the drone direction of travel at a distance of 1.0 m below the nozzle. The drone moved above the rod. The technical parameters of the drone movement while spraying the rod were the same as for spraying the trees. The same spray liquid was also used and the results were developed in a similar way using a photocolorimeter.

The test stand scheme for the measurement of the transverse distribution of the droplet stream is shown in Figure 3.

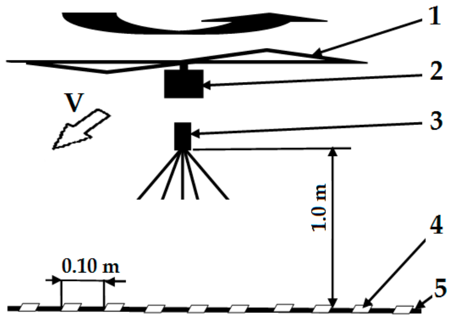


Figure 3. Test stand scheme for the measurement of the transverse distribution of the droplet stream: 1—propellers, 2—electric motor on multicopter branch, 3—spray nozzle, 4—samplers, 5—metal rod, V—drone speed.

3. Results

The results obtained from the measurements of the mass of the dye deposited were statistically analysed using Statistica software ver. 13.3 from StatSoft. The statistical analysis was used to assess the significance of the impact of the factors studied on the results obtained, and it was used for a presentation in the form of the graphs of the results, where they were presented including the calculated mean values and error ranges. Figures 4 and 5 present the results of the liquid (dye) distribution measurements on the samplers, at all of the levels depending on the distances between the trees: 0.5 m and 1.0 m, and depending on the rotational speed of the drone rotors: 0.0 and 6000.0 rpm. The diagrams were prepared for the results using an air-injector spray nozzle: the air-injector twin flat spray nozzle (Figure 4) and the air-injector flat spray nozzle (Figure 5).

The variance analysis found no significant impact of the distance between the trees (0.5 m and 1.0 m) on the amount of the dye deposited on the samplers, both at 0.0 rpm or 6000.0 rpm for both types of the nozzles. The significance coefficient calculated for these cases was greater than 0.05 and it was 0.083. This may be due to the small diameter of the tree crown and the slight overlap of the few branches, only at a distance of 0.5 m between the trees.

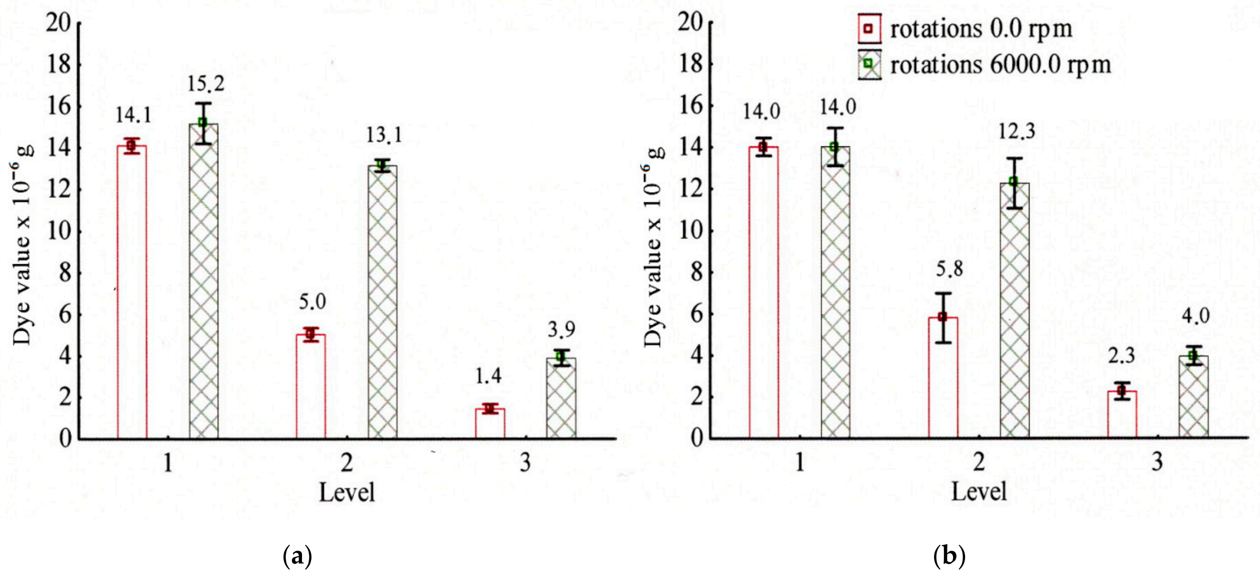
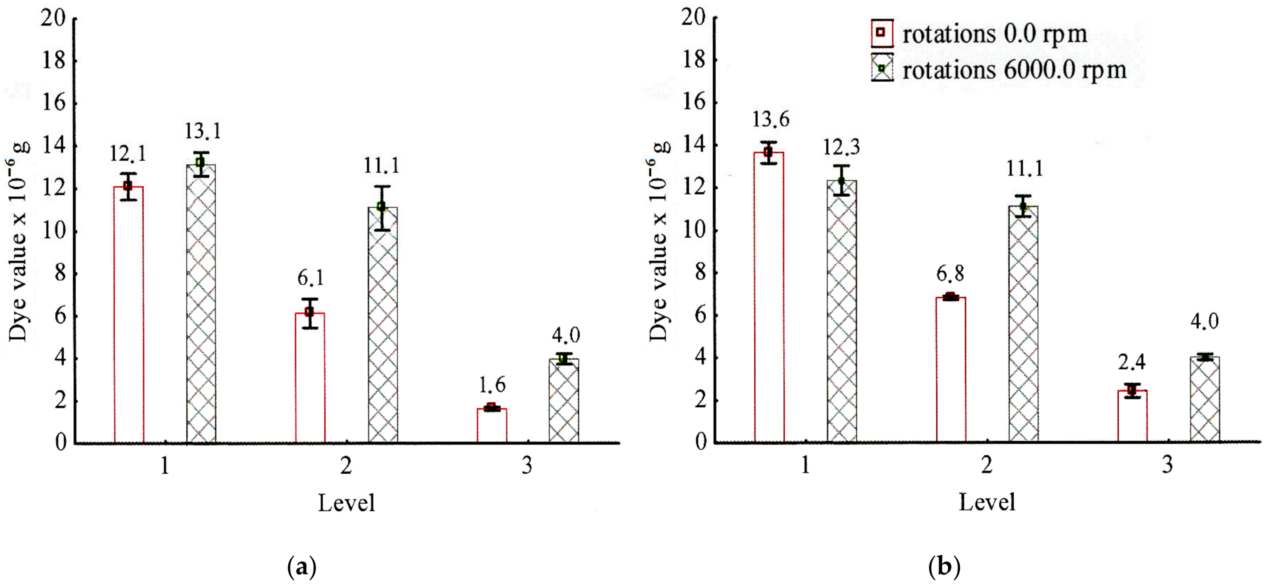


Figure 4. Distribution of the dye at individual levels of the tree crown depending on the distance between the trees and the rotational speed of the drone rotors at air-injector twin flat spray nozzle: (**a**) tree distance 0.5 m; (**b**) tree distance 1.0 m.

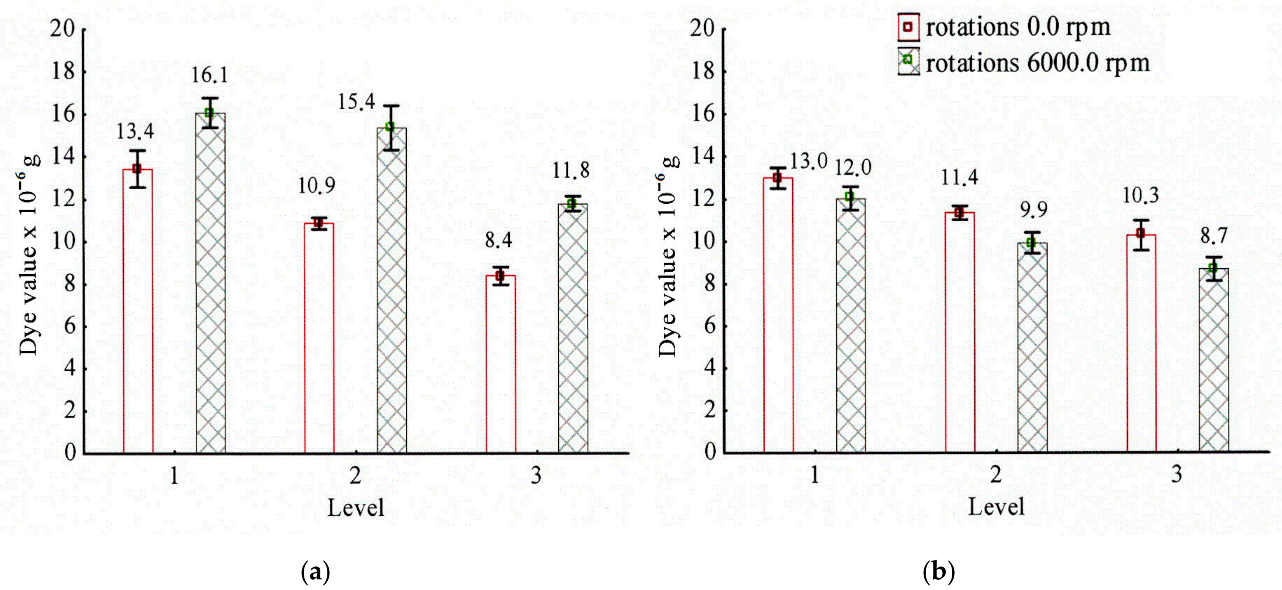


(**a**) (**b**)

Figure 5. Distribution of the dye at individual levels of the tree crown depending on the distance between the trees and the rotational speed of the drone rotors at air-injector flat spray nozzle: (**a**) tree distance 0.5 m; (**b**) tree distance 1.0 m.

It can be seen from the graphs that in each case, the air stream increased the amount of the fluid deposited on the samplers placed at levels "2" and "3", while no change was found in the amount of the fluid deposited at the upper level "1". Richardson and co-authors [49], using artificial trees made of plates to measure the distribution of liquid sprayed from a drone, also found no difference in liquid deposition on samplers at the trees distances of 0.5 m and 1.0 m.

The graphs in Figure 6 show the dye distribution on the samplers, placed on rods attached to poles but without trees. The impact of the nozzle type and the drone rotor speed on the amount of the dye deposited on the sampler levels is shown.



(**a**) (**b**)

Figure 6. Distribution of the dye on particular levels of the samplers, placed on rods attached to poles, without trees, depending on the nozzle type and the rotational speed of the drone rotors: (**a**) Air-injector twin flat spray nozzle; (**b**) Air-injector flat spray nozzle.

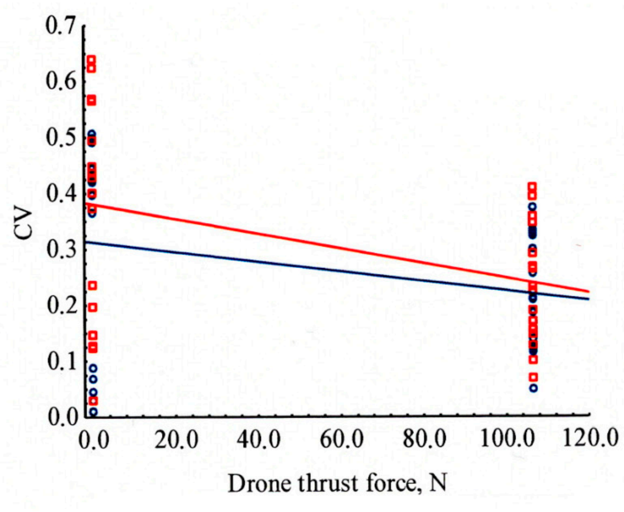
An analysis of variance revealed a significant and strong effect of rotational speed on the amount of the liquid deposited, $p = 0.0098$. There was also a significant impact of the nozzle type on the liquid deposition on the samplers, but solely for the rotors rotating at 6000.0 rpm, $p = 0.000004$.

The calculated aggregate value of the dye distribution at three levels, for each nozzle, for the cases when the samplers were placed in the tree and when there was no tree, is shown in Table 1. For the samplers placed in the tree, the aggregate value of the dye distribution is the average of both cases of tree spacing: 0.5 and 1.0 m. The table shows that the aggregate values of the liquid deposited on the samplers when the rotors are not working are similar or the same for both types of the nozzles; differences occurred only when the drone rotors were working. Significantly higher values of the liquid deposited on the samplers were obtained with the double-jet nozzles than with the single-jet nozzles.

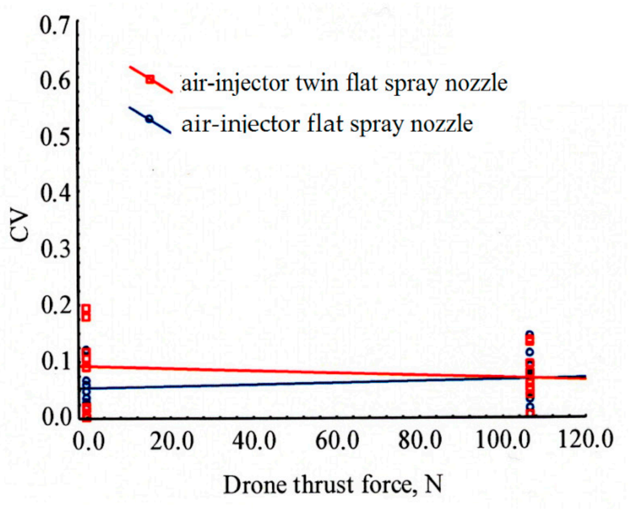
Table 1. Summary dye distribution calculated for three sampler levels.

Type of Air-Injector Nozzle	Twin Flat Spray Nozzle		Flat Spray Nozzle	
Rotations, rpm	0	6000	0	6000
Samplers inside of tree, 10^{-6} g	21.07 ± 2.26	31.23 ± 2.89	21.36 ± 2.34	27.81 ± 2.21
Samplers without tree, 10^{-6} g	32.72 ± 1.83	43.26 ± 2.30	34.66 ± 0.78	30.69 ± 2.51

Before performing the evaluation of the uniformity coefficient of the liquid distribution on the levels of the samplers, instead of the rotational speed of the rotors of the multirotor drone, the values of the thrust force produced by the drone at these rotations were introduced for the analysis. Instead of 0.0 rpm, a thrust force of 0.0 N was introduced, and instead of 6000.0 rpm, a value of 106.7 N was introduced. Next, using an analysis of variance an assessment was made of the significance of the impact of the thrust produced by the drone rotors on the uniformity of the liquid distribution on the samplers: CV. The results were also subjected to a regression analysis to determine a mathematical formula to describe the dependence of CV from the thrust force. Graphically, the results of the regression analysis are presented by means of a scatter graph in Figure 7.



(a)



(b)

Figure 7. Impact of the drone thrust on the uniformity of the liquid stream distribution at the levels with the samplers placed: (**a**) In the tree crown; (**b**) Without the tree crown (drone thrust 106.7 N—drone rotors rotation 6000 rpm).

As a result of the regression analysis, mathematical dependencies of the CV uniformity coefficient from the thrust force—x, N, were determined for the individual nozzles. For the samplers placed inside the tree crown, the following equations were obtained:

- for air-injector flat spray nozzle

$$CV = 0.3119 - 0.0009\ x \quad (2)$$

matching coefficient $R^2 = 0.0904$, significance factor $p = 0.0747$;

- for air-injector twin flat spray nozzle

$$CV = 0.3804 - 0.0013\ x \quad (3)$$

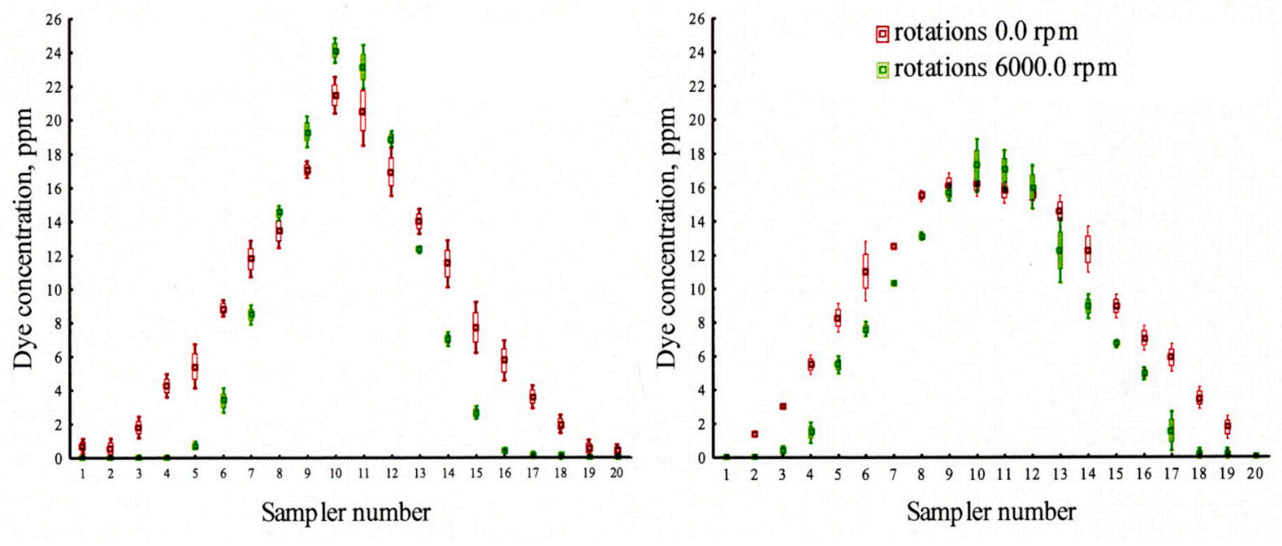
matching coefficient $R^2 = 0.1789$, significance factor $p = 0.0102$.

For the samplers sprayed without a tree crown, the presentation of the equations was omitted because no significant impact was found of the air stream due to the drone propellers on the uniformity of the liquid droplet stream distribution on the samplers:

- for air-injector flat spray nozzle significance factor $p = 0.4829$;
- for air-injector twin flat spray nozzle significance factor $p = 0.4198$;

The results of the analysis indicate a significant and positive effect of the thrust force and, thus, of the air stream coming from the rotations of the rotors, on the uniformity of the distribution of the liquid flow in the tree crowns when spraying with the twin flat spray nozzle. The impact of thrust force changes on CV values was accepted as a fact (see the graph), also when using the flat spray nozzle, although the significance coefficient, p value exceeded 0.05.

In order to clarify the reasons for the changes in the amount of the liquid deposited on the samplers and the changes in the uniformity of the liquid distribution in the crowns of the trees, under the influence of the air stream coming from the rotations of the drone propellers at 6000.0 rpm, tests were performed of the transverse distribution of the droplet stream under the spray nozzles used in this study. The results from the tests performed are presented in Figure 8.



(**a**) (**b**)

Figure 8. Impact of air flow from the drone propeller rotation on the transverse distribution of the liquid in the droplet stream: (**a**) Air-injector twin flat spray nozzle; (**b**) Air-injector flat spray nozzle.

The twin flat spray nozzle, compared to the single flat fan nozzle, produced a jet of droplets with a greater volume of the liquid in the central part of the jet. In both nozzles, the transverse width of the liquid distribution on the sampler and patternator narrowed under the influence of the air stream. The volume of the liquid deposited in the central part of the sampler increased, while the volume of the liquid deposited at the edges of the patternator decreased or it did not deposit at all. The narrowing of the droplet stream under the influence of the air stream from the drone rotors was due to changes in the shape of the droplet stream produced [42]. The droplet stream was not only affected by the air stream coming from the propellers above the nozzle but also from the adjacent rotors [43]. The droplet stream from the double-jet nozzle proved to be more susceptible to the impact of the flowing air.

The air blast narrowed the droplet stream causing them to thicken so that they could then penetrate deep in the tree crown. As a result of this phenomena, which occurs when trees are sprayed by a drone with rotating rotors, the volume of the liquid deposited at the middle and lower levels of the samplers placed in the crown of the cherry trees increased. The concentration of the droplet stream probably also had an impact on changes in the distribution of the liquid at the levels of the samplers when they were sprayed without any trees being present.

Some of the results of these studies, conducted with the drone's rotors in operation, showed a general similarity in the liquid distribution to the results of research carried out in orchards, presented in the works [26,27,37,38], where the coefficient of droplet distribution uniformity was also adopted for the deposition evaluation and where a similar arrangement of the samplers in the tree crowns was used. Unlike the assumptions made in the works cited above, the research presented in this paper focused on comparing the effect of nozzle type and the effect of the airflow produced by the rotors in order to overcome drone weight, on liquid deposition. No air-injector type nozzles were used in the cited studies. The nozzles used there were cone nozzles [38] and typical hydrodynamic single-jet nozzles Lu 120-15 and ST110-01 [26,27,37].

The cited studies also evaluated the effect of the shape of the tree canopy on the distribution of liquid. The trees used in this work were too young to shape their crowns. The crowns of the trees used in this study had a typical triangular shape with the point of edge facing upwards. In addition, it is very important that there were differences in the design and performance of the drones used in the cited articles, as well as in the placement of the nozzles on the drones. Other air raid parameters of the drones were also used when performing the treatments.

4. Conclusions

The results proved that the distribution of the liquid in the tree crowns depended on the weight of the drone. The air stream from the drone rotors, generating drone thrust, increased the volume of the liquid deposited on the trees sprayed. What mainly increased was the volume of the liquid deposited at the middle and lower levels of the tree crowns. The airflow produced by the rotors of the drone spraying the trees caused the stream of droplets to narrow and thicken. This improved the uniformity of the distribution of the liquid at the crown levels of the sprayed trees.

Of the two types of air-ejector nozzles: the single flat fan nozzle, IDK 120-02, and the twin flat fan nozzle, IDKT 120-02, used in the experiment, the drone air stream caused more liquid volume to be deposited in the tree crowns from the droplet stream produced by the twin-jet nozzle than by the single-jet nozzle.

The different spacing (0.5 m and 1.0 m) between young cherry trees had no significant effect on the volume of spray produced from the multirotor drone tested that was distributed inside the crown of trees.

The results of the research suggest that the uniformity of spray distribution in the tree canopy will be affected by the weight of the drone.

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