Design, prototype manufacturing and performance of a drone for vineyard spraying

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Abstract: The application of pesticides in vinyard areas is of crucial importance for grape yields. Field sprayers and atomizers are commonly used for pesticide applications in vinyards. The aim of this research is to develop a drone that will be an alternative to ground vehicles, to expand its use, to reduce the use of pesticides, as well as safer production with less pesticides in the environment, in vinyards area. In accordance to this purpose, a drone (unmanned aerial vehicle) with 6 motors and a multi-copter system (Hexacopter) was designed and prototype manufactured by using open source software program. The flight tests were carried out in the vineyard areas of Dicle University. In the experiments, water sensitive papers and filter papers were used to measure the amount of trace substance deposite rate and coverage rate. These papers were placed in the upper, middle and lower parts of the vine before started of the tests. Spraying experiments were then carried out at 0.5 m s^{-1}, 1.0 m s^{-1} and 2.0 m s^{-1} flight speeds and at different flight altitude such as 30 cm, 60 cm and 90 cm and different part of vine as upper, middle and lower part. Each test was carried out triplicated. According to results, spray deposition and coverage rates were found to decrease with increased flight speed of drone and flight altitudes. At all flight speeds and altitudes, the highest amount of deposite and coverage rate were found in the upper part of the vine, while this ratio decreased towards the lower region. The increase in the spray altitude was negatively affected the penetration of the droplets into the plant. In general, the best amount of trace material deposite and coverage rate were was obtained at 0.5 m s^{-1} flight speed of drone, 30 cm flight altitude and upper section of vine. While the amount of deposite in the plant at 0.5 m s^{-1} flight speed was obtained 19.62 µg cm^{-2}, this value decreased to 11.21 µg cm^{-2} at 60 cm altitude and 6.05 µg cm^{-2} at 90 cm flight altitude. As a result, we can argued that droplet distribution will be more homogeneous, droplet deposition effect well, and environmental pollution will be reduced, in the application of the remote-control drone and low ltitude sprayin, it also will play a very important role in the vinyard pest control.

Keywords: viticulture, precision agriculture, drone, UAV, design, spraying, deposition

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1 Introduction

Viticulture; it has been an important agricultural activity from the Neolithic periot to the present in the worldwide. The earliest evidence of grape vine cultivation and winemaking dates back 8,000 years. Various inputs are used to increase productivity and quality in viticulture. One of these inputs is pesticide application against diseases and insects. The application of pesticides in vineyards areas is of crucial importance for grape yields and quality. Agricultural pest control is still the key point of agricultural production of high production and top

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quality and the sustainable development of agricultural economy. In classical applications, both the desired success is not achieved and environmental pollution and cost are increase. The key to feeding the ever-increasing world population is the use of information and communication technology in agriculture. In the last decade, the applications of information technology, which is called precision agriculture, which is an alternative to classical agricultural practices has been begun in different fields of agriculture. To reach high quality of product, the adoption and use of unmanned aerial vehicles (UAV) is becoming increasingly common because of their speed and effectiveness in the spraying operation in vineyards (Comba et al., 2015). Also, to use of UAV in agriculture can contribute to the efficient management of agricultural farms. They have already found applications in precision agriculture, where they are replacing planes and satellites in the remote sensing of crops (Comba et al., 2015). To ensure the desired application rate of pesticide, one of the newest and most technological of precision agriculture applications is, instead of classical field sprayer, the use of drone applications for agricultural purposes (Zhu et al., 2010). The use of drones for spraying plants will allow for rapid application of plant protection agents on the growing areas (Berner and Chojnacki, 2017). Apart from the use of drones in activities that provide information in agriculture, they can also become part of agricultural machinery in future.

UAV, as emerging plant protection machinery, have the advantages of high operational efficiency, high speed, and low drift. Also, among the advantages of using drones in the fight against diseases and pests are the possibility of reaching the place where the operation will be carried out quickly and performing in a short time, as well as eliminating the problems related to compaction of the soil or wrinkling of the plants. In addition, since it will be used instead of tractor sprayers, the risk is reduced of poisoning of operator who perform spraying with pesticides. They can be particularly useful in the case of spot spraying over a large surface. Also, with use of drone in viticulture, an increase in economic benefits and a reduction of the environmental impact, fertilizers, pesticides and water needed by the soil or plant can be provided on time, in the desired amount and with the right methods (Berner and Chojnacki, 2017).

On the other hand, it can be shown as a disadvantage that it has a relatively high cost compared to ground equipment for effective spraying against diseases and pests, limited engine power, low storage capacities and affecting the quality of the work due to short flight distances. However, these disadvantages can be eliminated with existing ones or new designs Freeman and Freeland (2015) reported that although the potential of UAV to be used in agriculture is high, the operating range, flight times and payloads of UAVs currently used in agricultural applications are much less than that of advanced military drones. In other words, they are insufficient in terms of weight, size and energy consumption for the individual UAV itself and the sensors it carries. Also, they are easily affected by environmental factors; spraying and spraying with UAVs usually cause droplet drift. Therefore, droplet drift occurs because some of the dosage does not reach the target area during the application of pesticides (Kirk, 2000). Therefore, sufficient effectiveness is not provided in some areas of the field after chemical application with drones, due to high speed, sudden wind changes, weather conditions such as wind strength and direction during spraying, and the unevenness of the entire area to be sprayed. However, it is reported to show promise, especially with its low equipment cost, open source software, flight control intelligence and satellite-based navigation control. Similar studies on the possibilities of using drones for agricultural spraying and their performance for spraying were conducted by Giles and Billing (2014), Berner and Chojnacki (2017).

Lou et al. (2018) compared air vehicles with ground vehicles in terms of spraying efficiency in cotton spraying. They stated that the drop smoothness and residue ratio of the aircraft gave more satisfactory results than the ground vehicle (Hilz and Vermeer, 2013; Doering et al., 2014). A similar results were expressed by Koç (2017). Numerous similar studies has been conducted by Zhu et al. (2010), Şahin and Yıldırım (2011), Ru et al. (2011), Faiçal et al. (2014), Comba et al. (2015), Giles and Billing (2015), Kale et al. (2015), Rokhmana (2015), Huang et al. (2015), Ismail et al. (2020), Xue et al. (2016), Çolak et al. (2016), Wang et al. (2016), Teke et al. (2016), Wang et al. (2017), Zheng et al. (2017), Chen et al. (2017), Xu et al. (2017), Lou et al. (2018), Yallappa et al. (2017), Spoorthi et al. (2017), Berner and Chojnacki (2017), Kulbacki et al. (2018), Mogili and Deepak (2018), Baraniuk (2018), Wu et al. (2019), Anonymous (2019), Inoue (2020), Ochs (2020), Pathak et al. (2020).

With these negative features, in recent years, the usege of UAV in pesticide applications has become more common due to the fact that it does not harm the product, can move easily on sloping lands and has data storage and sending features for precision agriculture. So, drones can be used in small production areas an alternative to ground vehicles in different areas of agriculture, even though their batteries and engine power are limited. In addition, the wetland, mudflat, woodland and other special terrain doesn't suit the ground equipment operation. Therefore, only with the ground spraying equipment can not completely finish the pest control, the modern technology of unmanned aerial homework must be used to complete protection system. Considering the difficulties of spraying with ground vehicles, it has become necessary to popularize the use of this technology against diseases and pests in Turkey.

The objectives of this research are: 1) to design and manufacture a drone for spraying pesticide in vineyard, 2) to examine the pesticide deposit rate and coverage rate in vineyards depend on operating parameters such as different flight speeds and flight altitudes.

2 Materials and methods

2.1 Material

This study was carried out in two stages. In the first stage, it was aimed to design, manufacture of prototype. In the second stage, to determine the performance of drone that can pesticide spray in vineyard areas where ground vehicles cannot easily enter. For this purpose, a remote control drone with 6 motors and a multi-rotor system (Hexacopter) was designed and manufactured by using open source software program.

After the main body of the drone, which was laser cut according to technical dimensions, was formed, the main parts of the drone were assembled on this body, and the manufacturing process was completed and it became ready for flight. 5 liter capacity plastic tank was mounted on the drone frame. It has the ability to automatically land where it takes off by completing the spraying task in the specified field, vineyard or different areas, either with the help of the user or autonomously by giving GPS coordinates.

Vehicle tracking is transmitted from the camera mounted on the drone to the controller digitally at 640x480 resolution via radio waves. With the help of TYPE-C or Micro USB cable to the remote, live image transmission is provided via mobile phone, tablet, computer. Instant flight data of the vehicle; in order to calculate general parameters such as altitude, speed, battery information, distance to the take-off site, the open source Arducopter software, specially coded for this work, was used. All data specified with this software have a range of 20 km, and it also allows devices such as computers, Android-based mobile phones and tablets to be used as ground stations. This feature makes it useful even for people who have never used a drone in their life, to fly this vehicle autonomously after basic training and to fulfill the given tasks. This vehicle flight mission; it is provided with the help of 6 180KV 6205 type motors and 23 inch propellers (wings) made of carbon material connected to these motors (Figure 2). These soldered the motor connection cables and signal cables to the power distribution board as M1, M2, M3, M4, M5, M6 respectively. Three of these motors push clockwise and the remaining three move counterclockwise to provide thrust to the vehicle.

The power system of the drone consists of 120 pieces of 18650 Lithium-Ion type batteries (Samsung ICR18650-30A) with high discharge capacity. These batteries were connected as two cells in series with 10 parallel and these parallel units in groups of 6, and 2 battery groups as 6S10P were obtained. Since 12S=44.4 V is required in accordance with the engine factory data, two 6S10P battery groups that we have produced are connected in series to each other, and a battery group with a 12S10P capacity is obtained. The total voltage value is 50.2 volts and the capacity value is 20000 mAh. The Neo-M8N type GPS sensor was used in this study. The motor driver modules that control the motors on the drone were used. The ESC used in the drone controls the speed of the motors by converting the direct current energy system to alternating current. SKYDROID T12 model, 12-channel radio receiver, which enables remote control of the drone, was used. The Skydroid radio receiver is connected to the flight control board for data exchange connection and information transfer to the ground station. Apart from its ability to control the drone, this module also serves to transfer the instant flight data recorded on the flight control card to the user interface via bluetooth. Thus, it helps the user to follow instant flight data by connecting to the controller via Bluetooth protocol with the help of any android-based mobile phone or tablet.

A pump that can operate between 12VDC - 48VDC voltage values with adjustable flow intensity for spraying and spraying of the drone and 4 hydroulic spray nozzles for spraying has been used (Figure 1). As shown in Figure 1, nozzles were installed in drone.

Figure 1 Spraying pump and spray nozzles

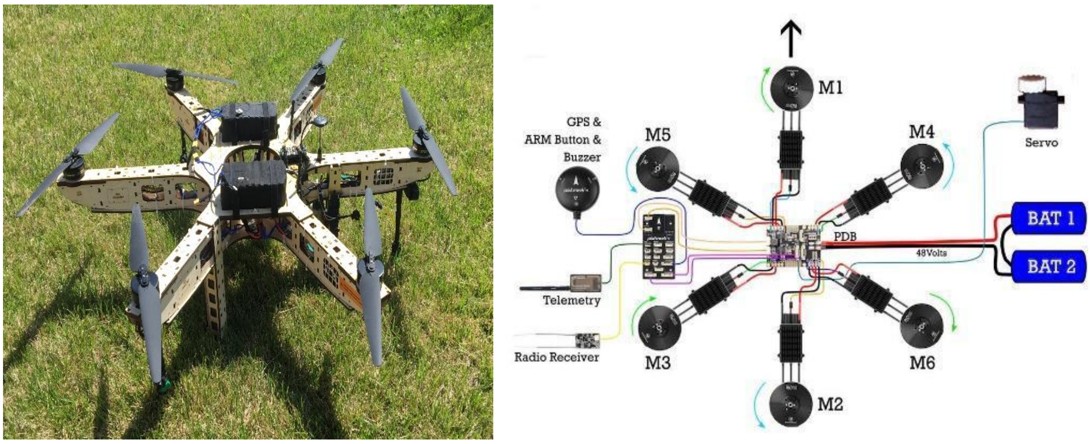

Figure 2 General view of the ready-to-fly drone with the connection diagram of the electronic components on the drone and its assembly and electronic connections

The connection diagram of the basic electronic components of the drone and the picture of the assembled body are given in Figure 2. Both batteries, manufactured as 6S, were connected in series to form a 12S battery group. The power obtained from the batteries is connected to the supply terminals of the distribution board. Each motor, in turn, provides the motor drivers with the correct voltage to the desired rotation directions as shown in the figure. The motor drivers are soldered to their places on the power distribution board programmed for them. The system is made operational by connecting the power connector on the power distribution board to the power1 input on the Pixhawk board for feeding and operating the boarding board. The connection of the electronic components required for the flight of the drone was completed by providing GPS and radio transmitter connections to the flight control card, respectively.

2.2 Method

After completed assembly, in the second stage, to determine of flight performence, the flight trials were carried out in the vineyard areas of Dicle University, Faculty of Agriclture, during the May in 2021, as shown in Figure 3. In the experiments, water sensitive papers and filter papers were used to measure the amount of trace substance and residue. Before starting the spraying experiments, these papers were placed in the upper, middle and lower parts of the vine (Figure 3). Spray trials were carried out at 0.5 m s^{-1}, 1.0 m s^{-1} and 2.0 m s^{-1} flight speeds and at three different flight altitude (30 cm, 60 cm and 90 cm) and with three replications (Figure 4).

Figure 3 View of the experience area and water sensitive papers on vine

Figure 4 Images during spraying operation

At the end of each trial, water sensitive the papers placed on different points in the vine foliage were collected and put into plastic containers (Figure 5), and their caps were closed. Samples were collected in the top, middle and bottom in the vines. Samples were dried and then, these containers were brought to the laboratory and 50 mL of distilled water was added to the containers containing the filter papers and the containers were shaken in the shaker (Figure 5). Trace substance deposition amounts of the samples obtained from different section of vine application were analyzed using the spectrophotometer device as shown in Figure 5. Tatrazine (E 102) was used as trace substance. Water-sensitive papers (TeeJet, Inc. Wheaton, IL USA), on the other hand, were scanned from the scanner and transferred to digital media as photographs. Then, these photographs were analyzed with the help of image processing software created in MATLAB program. The area covered by the droplets on the filter papers was measured and the obtained value was converted to % and the coerage rate values were found.

Figure 5 Plastic containers, spectrophotometer and shaker

2.3 Data analysis

Data were statistically analyzed using ANOVA test by the JMP software, version 13. The experiment was planned as factorial experiment in RCBD. The significance of mean values was analyzed using the Duncan multiple range tests and the means were compared at the p = 0.05 level of significance.

3 Results and discussion

The spray deposition results are presented in Figure 6. As shown in the Figure 6, the effect of flight speed, flight altitude and application region of vine plant has been found a significant on the deposite ratio (p<0.01). According to variance analysis and Duncan test results, there were found significant differences between the flight speeds, flight altitude and application region of vine plant (p<0.01). Spray deposition rate, as obtained by water sensitive papers analysis, was found to decrease with inreased flight speed of drone and flight altitudes.

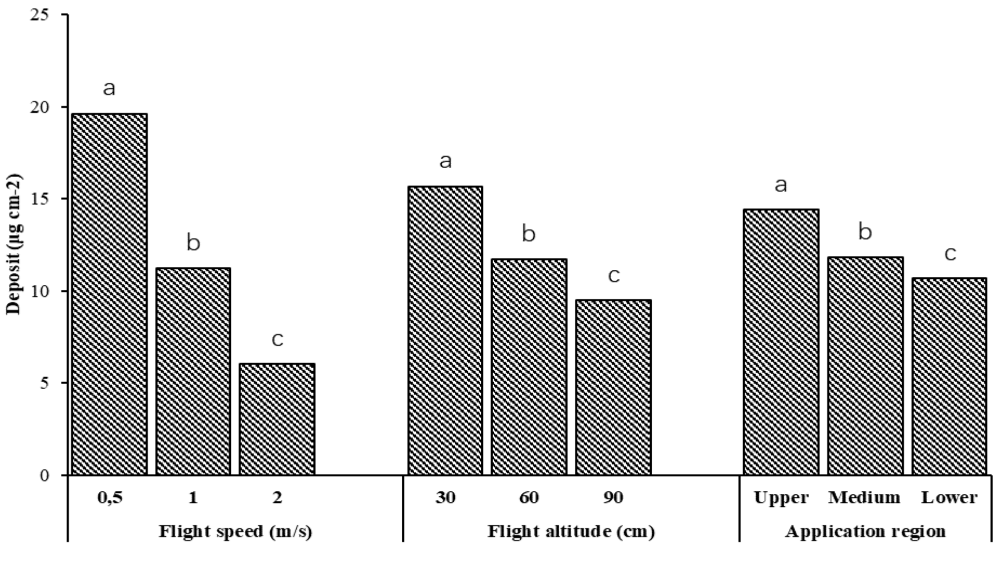

Figure 6 The change of trace substance deposit amount depend on drone flight speed, flight altitude and in the upper, middle and lower regions of the vine plant

Also, while the high trace substance was found top region in the vine plant, the low deposite found in lower reşgion of plant. While the high walue was obtained in upper part of the plant as14.41 μg cm^{-2}, the lowest deposite value was found as 10.66 μg cm^{-2} in lower section of the plant. The difference between the speeds was found to be statistically significant ($p<0.01$). The highest value was found at 0.5 m s^{-1} flight speed as 19.62 μg cm^{-2}, this value was obtained at 1 m s^{-1} as 11.21 μg cm^{-2} and at 2 m s^{-1} as 6.05 μg cm^{-2}, respectively. Generally, more deposite accumulation was found in the upper parts of the plant at all flight speeds and altitudes.

Especially, in the fly test in 30 cm altitude, the amount of trace material accumulation was found to be higher than the other altitudes. Also, according to results of variance analysis, the effect of interactions of selected operating parameters were found significant ($p<0.01$). The maximum deposite rate of interactions were obtained at 0.5 m s^{-1} flight speed, 30 cm alltitude and top region of vine plant as 24.43 μg cm^{-2}. This value is also the best result. This value was obtained as 2.63 μg cm^{-2} at 2.0 m s^{-1} flight speed, 90 cm flight height ve lower part of the plant decrease of approximately 10 times. While the highest amount of residue was formed in the upper part at all flight altitudes, this ratio decreased towards the lower part of vine. The reason of this can be explained as the distance between the spray nozzle and the target surface is greater. It is seen from Figure 6 that decreasing flight speed led to a increase deposite rate of trace accumaltion ratio. Wang et al. (2016) studied the effect of flight altitude and wind speed on droplet and flow distribution using an Unmanned Aerial Vehicle drone. They measured pesticide heritability by applying different tests. They reported that as the altitude and wind speed increased, the uniformity of drug distribution deteriorated and the drag increased.

Coverage rate are presented in the Figure 7. As shown in Figure 7, the coverage rate are affected significant by flight speed, flight altitude and application region ($p<0.01$). Duncan test result also showed that there were significant differences were found among selected independent parameters.

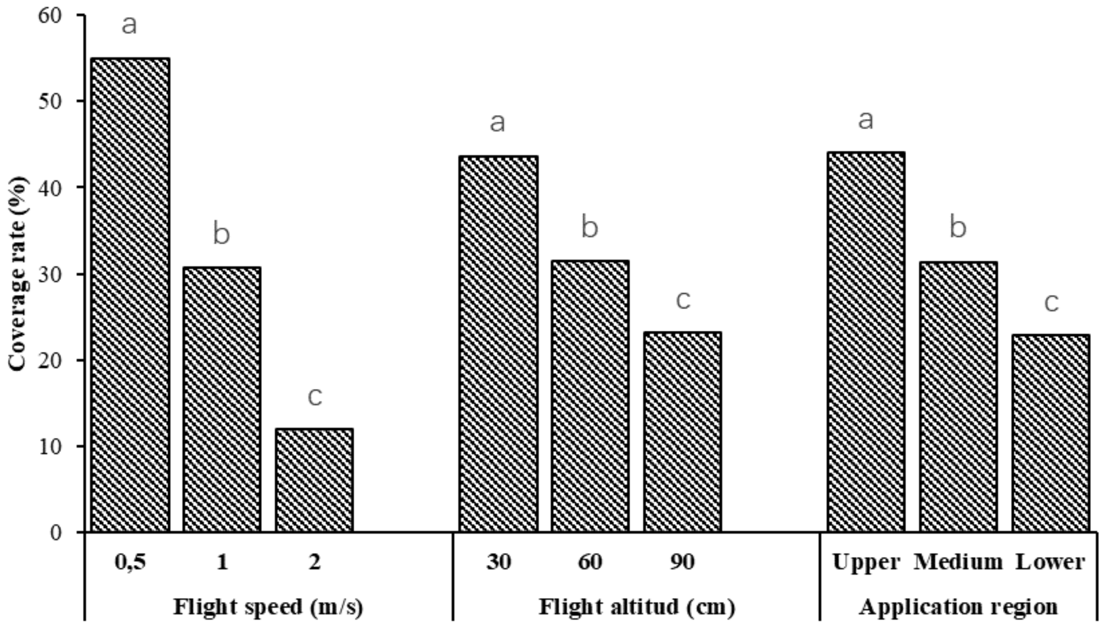

Figure 7 Coverage rate values measured in the upper, middle and lower regions of the vine plant at a speed of 0.5 m s^{-1}, 1.0 m s^{-1} and 2.0 m s^{-1} and at different flight altitude (30 cm, 60 cm, 90 cm)

The coverage rate decreased with an increase flight speed from 0.5 m s^{-1} to 2.0 m s^{-1}. This amount of decrease was also found to be very important in as statistics. While the highest coverage rate value was obtained at 0.5 m s^{-1} flight speed as 55 %, this value decreased as the speed increased. The coverage ratio value decreased at 1.0 m s^{-1} flight speed an it was found as 30.7%, and lowest value was obtained 2.0 m

s^{-1} flight speed as 23.19%. This situation showed that the flight speed and flight altitude are effected coverage rate of the pesticide on the plant. In this case, it should be applied pesticide at as low speeds and low heights as possible for a good coverage and distribution uniformity. Similar results were found by Koç (2017). Accoding to Koç (2017) surface coverage values decreased with increasing UAV speeds. Zhang et al. (2021) reported that when the flying height increases, the vertical velocity of the UAV downwash flow near the crop canopy will decrease (Zhang et al., 2021; Zhu et al., 2010). The downwash airflow of UAVs is the direct cause of the change in droplet penetration, and vertical wind speed has a greater effect than horizontal wind speed. Droplet penetration is positively correlated with the vertical velocity of airflow (Chen et al., 2017). Similar results were found by Giles and Billing (2015). According to these researcher, covarge rate decreases with rise of the drone flying speed.

The coverage rate was affected by flight altitude as well as flight speed (Figure 7). As can be seen from the Figure 7, as the flight altitude increased, the coverage ratio decreased and the trace substance coverage rate was found the highest in the upper part of the plant. Depending on the flight altitude, the coverage ratio varied between 43.63% and 23.9%. While the maximum value was obtained at 30 cm height as 43.63%, the coverage ratio decreased to 31.48% at 60 cm altitude and to 23.9% at 90 cm altitude. According to Duncan test results, tehere were found statistically significant differences between flight altitude (p<0.01).

The results of the analysis of variance and Duncan's test also showed that the effect of interactions of speed, alttitude and plant region were found significant as statistically (p<0.01). There were found significant differences between all selected interactions parameters. The highest and best trace material coating rate were obtained at 0.5 m s^{-1} flight speed, 30 cm altitude and upper region of plant as 82.33%. The lowest and worse coverage rate were obatined at 2.0 m s^{-1} flight speed, 90 cm alltitude and lower region of plant as 3.33%. This change was approximately 25 times. These data are important for selecting suitable spray nozzles for vineyard. Because, the selection of suitable operating parameters such as flight speed, altitude and spraying nozzle will be play an important role in optimizing the application rate of pesticides and more efficient application. Acoording to Terra et al. (2021) select of correct nozzle is to reduce the amount of pesticides applied in crops, not just for potential savings for the farmers, but also for environment protection issues, as well as for food safet. These results also are in agreement with Giles and Billing (2015).

4 Conclusions

The tests results indicated that the deposite rate and coverage ratio are affected selected operating parameters. The best results were obtained at 0.5 m s^{-1} flight speed, 30 cm flight altitude and upper region of plan both deposite rate and coverage rate.

As a result; It has been seen that this unmanned aerial vehicle, the drone, whose design and manufacture was carried out by us using an open software program, is more economical than the imported ones. It has been seen that this drone can be further developed and produced locally and contribute to the development of the agricultural mechanization sector. In addition, since the operator is in control during applications with this tool, human labor will be reduced, application errors will be reduced, the application dosage of the pesticide applied to the plant will be applied on time and as needed. The negative impact of cost and the environment will be reduced, as well as the residues will be reduced accordingly. Since an effective spraying will be applied in the vineyards, the quality of grapes and products obtained from grapes will increase. Since the contact of the administered drug with the human is almost absent, the negative effects of the applied drug on human health will be eliminated. This will both increase the added value of the product and eliminate the negative effects that affect human health. Therefore, it has been seen that it will make serious contributions to the spread of precision agriculture in areas that are difficult and tiring in the vineyard areas and where people and traditional machines cannot easily enter.

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