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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Determination of the Application Parameters of Spraying Drones for Crop Protection in Hazelnut Orchards

Fındık Bahçelerinde Bitki Koruma Uygulamalarında İlaçlama İçin Kullanılan İnsansız Hava Araçlarının Uygulama Parametrelerinin Belirlenmesi

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Abstract

Hazelnut, which has the most common cultivation area after almonds and walnuts among the shell fruits in the world, contains high levels of fat, protein, carbohydrates, various minerals and vitamins. Hazelnut has a broad growing area around the world, and Turkey accounts for 58% of world production with 776,000 tons annually. With this production capacity, Turkey ranks first in hazelnut production over the world. Harmful insects in hazelnut trees are the main factors that reduce hazelnut yield and quality. Pesticides are sprayed with backpack sprayers in the fight against these pests in hazelnut trees. Farmers are directly exposed to pesticides in these practices, which use high amounts of pesticides and water. In recent years, the use of unmanned agricultural vehicles in agriculture has increased. Drones are also used in pesticide applications in agriculture. In this study, the suitability of pesticide applications with the drone in hazelnut fields in Giresun province in terms of field conditions and spraying efficiency was investigated. In September 2021, applications were made with DJI Agras MG-1P model spraying drone in a selected hazelnut orchard in Uzgur village of Giresun province. The drone has 4 Teejet XR11001VS fan jet nozzles. Water-sensitive papers were placed on different regions on the hazelnut trees to be sprayed for drop measurements. In the experiments, hazelnut trees were sprayed using water at different heights and spraying rates. 6 flights were carried out at 1.5 and 2 meters altitudes and 1, 2 and 3 $L.da^{-1}$ spray rates, and three hazel trees were sprayed as three repetitions in each flight. After the flight trials, the water-sensitive papers were scanned on the scanner, and the volume median diameters and the number of droplets per square centimetre were calculated in the DepositScan software. As a result of the analyses done, it was observed that the applications performed at 1 $L.da^{-1}$ and 2 $L.da^{-1}$ spray rates would not be sufficient in terms of spraying efficiency. As the drone flight altitude increased, the accumulation of the drops on the inner leaves decreased. In terms of drop distribution, the most homogeneous application parameter was found to be 1.5 meters high above the upper leaves of the hazel trees and 3 $L.da^{-1}$ spray rate.

Keywords: Hazelnut, Drone, Spraying, Volume median diameter, Pesticide, Droplet

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Öz

Dünyada kabuklu meyveler arasında badem ve cevizden sonra en yaygın ekiliş alanına sahip meyve olan fındık, içerisinde yüksek oranda yağ, protein, karbonhidrat, çeşitli mineraller ve vitaminler içermektedir. Fındık, dünyada geniş bir yetişme alanına sahiptir ve Türkiye, yıllık 776.000 ton üretimle dünya üretiminin %58'ini karşılamaktadır. Bu üretim kapasitesi ile Türkiye, dünyada fındık üretiminde birinci sıradadır. Fındık ağaçlarında zararlı böcekler, fındık verimini ve kalitesini düşüren etmenlerin başlıcalarıdır. Fındık ağaçlarında bu zararlılarla mücadelede sırt pülverizatörleri ile pestisit uygulamaları yapılmaktadır. Yüksek miktarda ilaç ve su kullanımı ile yapılan bu uygulamalarda, çiftçiler direkt olarak pestisitlere maruz kalmaktadır. Son yıllarda insansız tarım araçlarının tarımda kullanım alanı artmıştır. İnsansız hava araçları tarımda pestisit uygulamalarında da kullanılmaktadır. Yapılan çalışmada Giresun ilindeki fındık arazilerinde insansız hava araçları ile pestisit uygulamalarının arazi koşulları ve ilaçlama etkinliği açısından uygunluğu araştırılmıştır. 2021 Eylül ayında Giresun iline bağlı Uzgur köyünde seçilen bir fındık bahçesinde DJI Agras MG-1P model ilaçlama için kullanılan insansız hava aracı ile uygulamalar yapılmıştır. İnsansız Hava Aracı üzerinde Teejet XR11001VS yelpaze hüzmeli memeler kullanılmıştır. Püskürtme yapılacak fındık ağaçlarının üzerindeki farklı bölgelere damla ölçümleri için suya duyarlı kağıtlar yerleştirilmiştir. Denemelerde farklı yükseklik ve ilaçlama normlarında fındık ağaçları üzerine su kullanılarak püskürtme yapılmıştır. 1.5 ve 2 metre yüksekliklerde ve 1, 2 ve 3 $L.da^{-1}$ püskürtme normlarında toplam 6 uçuş gerçekleştirilmiş, her uçuşta üç tekerrür olarak üç adet fındık ocağı ilaçlanmıştır. Uçuş denemelerinden sonra suya duyarlı kağıtlar yazıcıda taranarak DepositScan yazılımında ortalama damla çapları ve santimetrekaredeki damla sayıları hesaplanmıştır. Yapılan analizler sonucunda, 1 $L.da^{-1}$ ve 2 $L.da^{-1}$ püskürtme normunda yapılan uygulamaların ilaçlama etkinliği açısından yeterli olmayacağı gözlenmiştir. İHA uçuş yüksekliği arttıkça damlaların iç yapraklardaki birikimi azalmıştır. Damla dağılımı açısından en homojen uygulama parametresi 1.5 metre yükseklikte ve 3 $L.da^{-1}$ püskürtme normu olarak bulunmuştur.

Anahtar Kelimeler: Fındık, İnsansız hava aracı, Drone, İlaçlama, Hacimsel ortalama çap, Pestisit, Damla

1. Introduction

Nuts (*Corylus avellana L.*) are the third fruit with the most common production area after almonds and walnuts among nuts (Bars, 2018). It contains 64% vegetable oil, 16.5% protein, 14% carbohydrates, various minerals and vitamins (Anıl et al., 2018). There is 634 kcal energy in 100 gr hazelnuts which can meet 22% of the daily protein needs of an adult. It has a wide cultivation area throughout the world as Southern and Eastern Europe, Central Asia, North Africa, and America. With an annual production of 776000 tons, Turkey meets 58% of the world's consumption and ranks first in the total production amount (Anonymous, 2020a). Hazelnut cultivation in Turkey is most common in Ordu, Giresun, and Samsun in the Eastern Black Sea Region; in addition, 386194 quarries exist in the provinces of Sakarya and Düzce (Anonymous, 2020b).

Harmful insects seen in hazelnut orchards are at the top of the factors that reduce the yield and quality of hazelnut (Uzundumlu et al., 2017). Around 250 hazelnut pests have been detected worldwide, causing a vital economic loss (Kılıç, 2014). Hazelnut Skunk (*Palomena Prasina L.*) and Nut worm (*Curculio nucum L.*) are two species with the highest damage level in Turkey (Ateş and Kaçar, 2021). Öztürk and Islam (2019), in their study in old and new hazelnut production areas, reported that producers struggled against pests such as powdery mildew, hazelnut worm, wood borer, cone mite, hazelnut sprout moth.

Chemical control against pests in hazelnut trees is usually carried out with a back sprayer for reasons such as the uneven terrain of the lands and irregular tree arrangement. As the terrain slope increases in hazelnut orchards, the use of pesticides also increases (Uzundumlu et al., 2017). Although these pesticide applications are effective, the damage to living and the environment has always encouraged researchers to develop new techniques (Çelen et al., 2020). To cover every surface of the trees, farmers apply pesticides using excess water and pesticides. In this case, both economic and environmental damages occur with excessive pesticide use, and non-target areas are also exposed to pesticides with spray drift. In addition to these problems, the farmers who spray with the backpack sprayer should wear suitable clothes, masks, gloves, etc. In cases where they do not use protective clothing, they are directly exposed to the sprayed chemical. This situation causes health problems both in the short and the long term.

Unmanned aerial vehicles have been helping manufacturers in agriculture for many years. As the developing technology increases the efficiency of drone components such as batteries, control, and propellers, their use in agriculture has become even more economical and attractive. Today, drones are used in agriculture for remote sensing, monitoring of pests and plant health, fertilization, and spraying. In the production of field and horticultural crops, a drone equipped with a multispectral camera takes images on the land with a camera. A field map is created with those images, and it can be determined in which region the plants are healthy and in which they are unhealthy. Alike, cameras can detect the rust spots on the leaves, and fungal diseases can be prevented. Besides, drones also detect the health of the soil with remote sensing (Sari, 2022). In addition to its imaging function, drones also find a place in agriculture in the field of application. Especially in recent years, aerial spraying has been made possible by mounting a small liquid tank, pump, and spray nozzles on drones. Thus, drones can apply pesticides in cases where it is difficult to enter the field with a tractor or various spraying equipment (Çelen et al., 2020).

The use of drones in pesticide applications has begun to find a place in all kinds of agricultural production. Research on this subject has spread to the entire field of agricultural sciences. The efficacy of pesticide applications for horticultural crops has also been investigated in recent years. Relatively low amounts of water used during spraying application by drones have made the research on the effectiveness of the spray widespread. Li et al. (2021) applied pesticides at two different spray rates (46.8 L ha^{-1} and 93.5 L ha^{-1}) with drones to fight against Scolytinae on almond trees and compared spray deposition and surface coverage values with an air-assisted sprayer. As a result of the study, they stated that while there was more spray deposition on the lower leaves in ground spraying, there was more spray deposition on the upper leaves in the application with a drone. Considering the biological efficacy of the application, they concluded that both applications managed to keep the effect of the Scolytinae below the economic damage threshold. The researchers stated that with a proper spray rate and height adjustment, drones can be used in horticulture, but more studies are needed to be performed. Chojnacki and Pachuta (2021) investigated the effects of different parameters on the droplet distribution of pesticide applications with drones in cherry trees. In the study, the downwash effect created by the propellers affected the droplet distribution, allowing the pesticide to deposit more in the middle and lower parts of the tree. In the application made with twin-angle spray nozzles, more pesticide deposition was observed compared to the application with a single-outlet spray nozzle. The authors concluded that the downward thrust created by the propellers of the drone had a positive effect on the distribution of droplets in the trees. Irfan et al. (2021) examined the droplet distribution in pesticide applications with drones on mango trees. They stated that the shape and structure of the tree also had a significant effect on the droplet distribution besides the drone parameters. As can be deduced from the research, the effectiveness of pesticide applications in pesticide applications by drones in orchards varies depending on the flight route, flight speed, height, pesticide rate, droplet size, tree shape, and plant spacing (Wang et al., 2019).

The irregular and sloping terrain in hazelnut orchards and low efficacy of the ground spraying have made drone use for spraying purposes in hazelnut orchards in the Black Sea Region attractive. The operator can control the spraying drone with the remote control from the outside without entering the hazelnut orchard. In this way, both faster and safer spraying can be practiced on sloping lands, and the operator is not directly exposed to pesticides as ground spraying.

It was aimed to investigate the suitability of pesticide applications with drones to reduce the adverse impacts of various pests in hazelnut orchards in the Black Sea Region, in terms of field conditions and spraying efficiency.

2. Materials and Methods

Drone spraying trials in hazelnut (*Corylus colurna*) orchards were carried out in a hazelnut orchard in Uzgur Village of Giresun province in September 2021 at the coordinates of 40 53' 12'' North 38 21' 28'' East *(Figure 1)*. In order to eliminate the influence of the wind and temperature on spraying quality, spraying trials were carried out in a day with calm and clear weather. In addition, temperature, humidity, and wind speed values were recorded during the applications.

Figure 1. Satellite Image of the Trial Site

DJI Agras MG-1P model spraying drone was used. This spraying drone has 8 rotors, and each rotor has 2 propellers. There is a 10-liter chemical tank on it, and the pesticide is sprayed from 4 spray nozzles with 2 electric diaphragm pumps. Spray nozzles are Teejet XR11001VS flat fan nozzles with 110-degree spray angle, which are preferred in ultra-low volume spraying applications generally used in drones *(Figure 2)*. According to catalogue values, 1-hectare area can be sprayed with a 10-minute flight at 10 L ha^{-1} spray rate.

The spraying drone is controlled by a licensed operator with a remote control device. Before starting the application, the operator determines the boundaries of the area by walking around, thanks to the GPS in the remote control device. Then land borders, flight parameters, and spray rate on the screen on the remote control device are set. When the application begins, the spraying drone automatically takes off and sprays pesticide on the route created before. To assist this automatic flight, the drone has a built-in GPS and a radar system used to help it avoid obstacles. Radars are positioned on the front, back, and side of the drone. The front and rear radars detect the slope of the terrain and ensure that the height of the drone remains constant relative to the ground. The radar on the side allows for a more precise height adjustment. Although the precision of the GPS on the drone is about 2 meters during flight, this value is not enough to prevent overlaps and stay on the flight path. To provide more precision, an external RTK station connected to the spraying drone and the remote control device simultaneously during the flight is used. Thanks to this station, the position precision of the spraying drone increases to 2-3 cm. The technical specifications of the spraying drone are shown in *Table 1*.

Table 1. Technical specifications of DJI Agras MG-1P model spraying drone

Features	Values
Total Weight	9.7
Dimensions (mm)	1460 × 1460 x 578 mm (arms open, without propeller) 780 × 780 × 578 mm (arms closed)
Maximum Power Consumption (W)	6400
Airtime (minutes)	20
Lowest Height Over Plant (mm)	1500
Type and Number of Spray Nozzles	Teejet XR11001VS 4 pcs
Flow rate of spray nozzles (l sec^{-1})	0.379
Tank Capacity (liter)	10
Spray Width (m)	4
Maximum Spraying Rate (m s^{-1})	7
Maximum Flight Speed (m s^{-1})	12
Battery Capacity (mAh)	12000
Battery Weight (kg)	4

	bar	DROP SIZE 80°	DROP SIZE 110°	CAPACITY ONE NOZZLE IN l/min	l/ha 50 cm 4 km/h	5 km/h	6 km/h	7 km/h	8 km/h	10 km/h	12 km/h	16 km/h	18 km/h	20 km/h	25 km/h	30 km/h	35 km/h
XR8001 XR11001 (100)	1.0	F	F	0.23	69.0	55.2	46.0	39.4	34.5	27.6	23.0	17.3	15.3	13.8	11.0	9.2	7.9
	1.5	F	F	0.28	84.0	67.2	56.0	48.0	42.0	33.6	28.0	21.0	18.7	16.8	13.4	11.2	9.6
	2.0	F	F	0.32	96.0	76.8	64.0	54.9	48.0	38.4	32.0	24.0	21.3	19.2	15.4	12.8	11.0
	2.5	F	F	0.36	108	86.4	72.0	61.7	54.0	43.2	36.0	27.0	24.0	21.6	17.3	14.4	12.3
	3.0	F	F	0.39	117	93.6	78.0	66.9	58.5	46.8	39.0	29.3	26.0	23.4	18.7	15.6	13.4
	4.0	F	VF	0.45	135	108	90.0	77.1	67.5	54.0	45.0	33.8	30.0	27.0	21.6	18.0	15.4

Figure 2. Features of Spray Nozzles

In order to observe how the droplet distribution changes at different heights and spraying rates in the trials, spraying was carried out at two different heights (1.5 m - 2 m) and 3 different spray rates (1 L da^{-1} - 2 L da^{-1} - 3 L da^{-1}). The height values were considered as the distance from the upper leaves of the hazelnut trees, and the values of the spray rate were set from the menu on the remote-control device screen. It was applied as three repetitions for each height and spray rate value. The trial plan is shown in *Table 2*.

Table 2. Trial Plan

Trial No.	Height (m)	Spraying Rate (l da^{-1})	Code	Pressure (bar)
1	1.5	1	A1	0.5
2	2.0	1	A2	0.5
3	1.5	2	B1	0.5
4	2.0	2	B2	0.5
5	1.5	3	C1	0.5
6	2.0	3	C2	0.5

In order to examine the droplet distribution in hazelnut orchards with a drone, water-sensitive papers measuring 26 x 76 mm were used (Anonymous, 2022a)

For this purpose, the spraying drone sprayed three hazelnut trees in a single flight. After the take-off, the drone flew on the left side of the tree line, turned back from the end of the tree line, and continued flying on the right side of the tree line. During each trial, the drone took off from the starting point, started spraying at a distance of

5 meters from the trees in the planned route, after turning from the end of the tree line, it returned by spraying, stopped spraying at a distance of 5 meters from the tree line and returned to the starting point *(Figure 3)*. The reason for creating a 5 meters buffer zone is to avoid the effect of the irregularity of the water rate that comes to the nozzles during the cut-off stage.

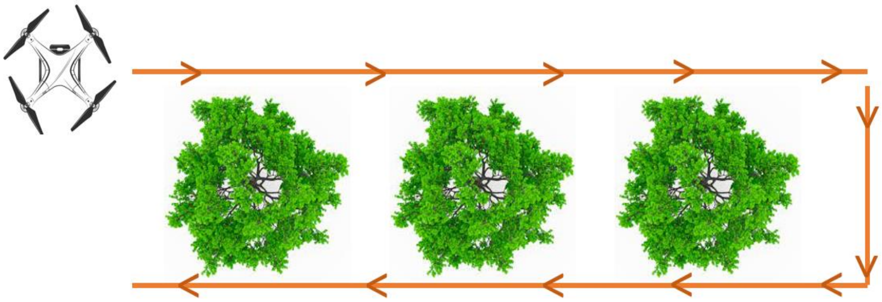

Figure 3. Flight route of the drone

In order to monitor the distribution of droplets delivered to different regions on the hazelnut tree, each tree was divided into 9 separate sections on the horizontal and vertical axis, and a water-sensitive paper was attached to a leaf with paper clips in each section. The separated regions on the tree are shown in *Figure 4*.

After each flight, the water-sensitive papers on the sprayed trees were collected and placed in sealed packages. After the test flights were over, all water-sensitive papers were scanned in a scanner at 600 dpi resolution and transferred to the computer. By using DepositScan software, droplet diameters, percentage of spray coverage, number of droplets per unit area, and the total number of droplets on water-sensitive papers were calculated (Zhu et al., 2011). The values measured on water-sensitive paper belonging to an experiment were transferred to Excel and graphed and the Coefficients of Variation were calculated.

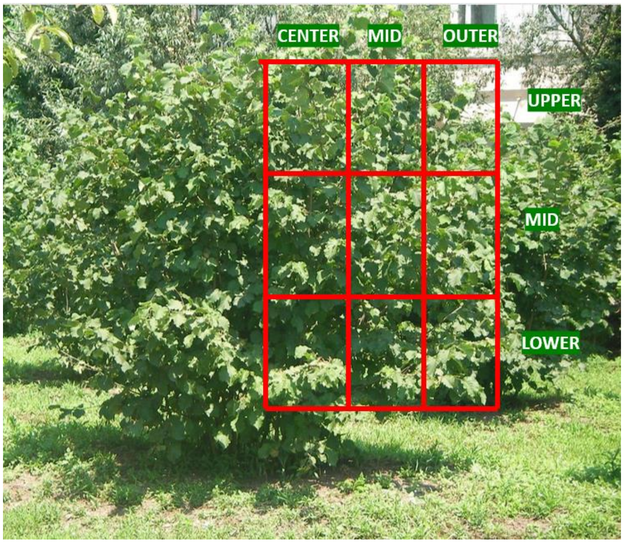

Figure 4. Regions Where Water Sensitive Papers Are Placed

3. Results and Discussion

A total of 6 flights were executed with the drone, and three hazelnut trees were sprayed in each flight to perform three repetitions. In total, 162 water-sensitive papers were collected from 18 trees. Droplet analyses were performed in DepositScan software and graphed in the Excel program. In the droplet analysis, $Dv_{0.1}$, $Dv_{0.5}$, $Dv_{0.9}$ values, the number of droplets per cm ^{2}, the variation of the coverage percentages with the flight altitude and spray rate were examined, and the coefficients of variation were calculated.

Table 3 shows the average droplet diameters of the droplets deposited on water-sensitive papers as the result of the trials. According to these results, the lowest average droplet diameter of 238 µm was obtained in the A2 trial, and the highest average droplet diameter of 341 µm was obtained in the A1 trial. According to international droplet classification criteria (Anonymous, 2022b), these droplet diameters vary between medium and coarse sizes. Although the promised droplet size is stated as "fine" in the catalogue of the spray nozzle used, the droplets are larger than normal due to low pressure, since spraying is performed at ultra-low spray rates and low pressures.

Table 3. Change of volumetric mean diameter $Dv_{0.5}$ values (µm)

	OUTER	MIDDLE	CENTRE		OUTER	MIDDLE	CENTRE
		A1				A2	
UPPER	322.5	310	266.5	UPPER	355	240	224.3
MIDDLE	343	300	294.5	MIDDLE	235.6	257.6	174
LOWER	332.5	584	316.6	LOWER	185.3	254.3	217.3
		B1				B2	
UPPER	299	382	455.6	UPPER	305.5	313.25	356.75
MIDDLE	412	268	340.6	MIDDLE	295.25	339	288.75
LOWER	294	260	331.6	LOWER	256.25	283.75	289.75
		C1				C2	
UPPER	144	219.3	314.3	UPPER	422	333	302
MIDDLE	333	268.6	353	MIDDLE	262.6	377.3	150.6
LOWER	292	262.3	285	LOWER	302	400	265.6

The lowest coefficient of variation obtained was 9% in trial B2, and the highest was 27% in trial A1. The coefficient of variation of all trials was calculated as 13%. According to these results, it can be said that there is uniformity in the mean droplet diameters. *Table 4* shows the droplet densities on the water-sensitive papers calculated with the DepositScan software.

Table 4. Change in the number of droplets in cm^{-2} (number of droplets cm^{-2})

	Outer	Middle	Centre		Outer	Middle	Centre
		A1				A2	
Upper	10.0	11.4	2.0	Upper	3.9	7.7	6.9
Middle	9.9	11.5	5.5	Middle	3.1	6.7	5.0
Lower	7.2	16.3	5.9	Lower	1.1	1.5	3,4
	Average	Standard Deviation	Variation Coefficient		Average	Standard Deviation	Variation Coefficient
	8.9	4.2	47.4		4.4	2,4	54.3
		B1				B2	
Upper	17.3	41.5	20.2	Upper	16.2	31.7	8.4
Middle	14.7	4.9	14.7	Middle	17.1	9.0	5.7
Lower	14.2	13.6	6.4	Lower	7.6	8.9	11.1
	Average	Standard Deviation	Variation Coefficient		Average	Standard Deviation	Variation Coefficient
	16.4	10.6	64.6		12.9	8.0	62.5
		C1				C2	
Upper	23.0	15.8	17.1	Upper	42.0	20.8	1.6
Middle	16.6	10.0	16.6	Middle	19.3	30.6	2.1
Lower	17.0	14.2	16.8	Lower	7.7	16.6	6.4
	Average	Standard Deviation	Variation Coefficient		Average	Standard Deviation	Variation Coefficient
	16.3	3,4	20.6		16.3	13.6	83.3

According to these results, the highest droplet density was obtained in trials C1 and C2, where the highest spray rate per hectare. In regards to the coefficients of variation, the highest value was obtained with 83.3% in trial C2 and the lowest value with 20.6% in trial C1. Considering the coefficients of variation in other trials, the only value that can achieve uniformity is the spray application made at a spray rate of 3 L da^{-1} and from a height of 1.5 meters.

Considering the 3D graphics in *Figure 5* and the droplet density results in *Table 4*, it is seen that the droplet density increases towards the upper and outer leaves of the trees. In drone flight parameters, the altitude value is loaded to the controller and drone based on the height from the ground. To spray at a distance of 1.5 meters from the upper leaves of the tree, the height of the hazelnut trees was considered as 4 meters and the drone altitude was set as 5.5 m. At different tree heights, the drone was able to maintain the distance determined with the help of radar and distance sensors. However, the decrease in droplet deposition on the lower and central leaves is because of the low penetration ability of the droplets produced by the drone. In addition, tree height and leaf density also disable the droplets to reach the inner and central leaves. When the flight distance is upgraded to 2 meters from the upper leaf, droplet densities in A2, B2, and C2 trials are lower than in A1, B1, and C1 trials, which is another result of the low penetration ability.

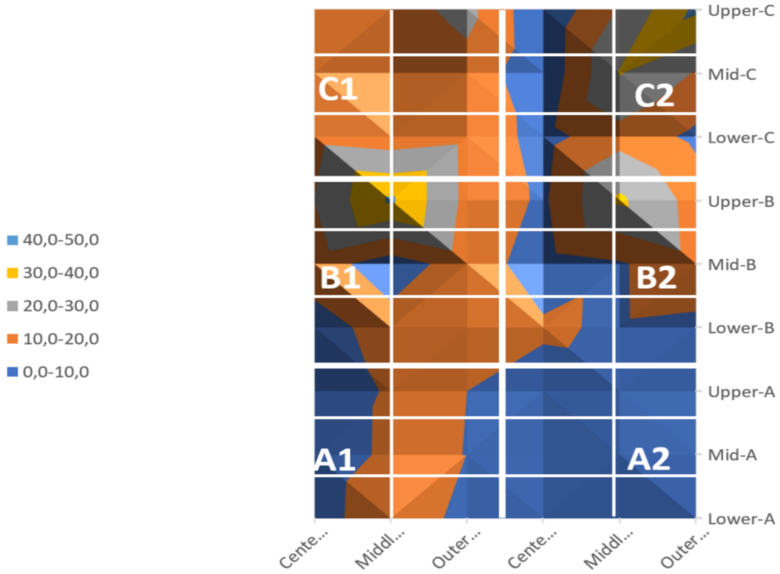

Figure 5. Number of droplets per cm ^{2} accumulated in different parts of hazelnut trees in the experiments

In the A, B, and C trials, it was observed that when the spray rate increased, the droplet densities also increased. While droplet densities reached the lowest values as 1.1-6.9 droplets cm^{-2} in trial A2, they reached the highest value as 10-23 droplets.cm^{-2} in trial C1. Although densities in the range of 16-42 droplets cm^{-2} were observed in the middle-outer parts in the C2 trial, low depositions were obtained in the inner and central parts. These obtained values raise doubts about the biological efficacy that may occur in the application of pesticides by drone. In *Table 5*, the minimum droplet densities required for biological efficacy in different pesticides according to Syngenta Crop Protection AG are shown.

Table 5. Minimum droplet densities required for biological activity in different pesticides (Syngenta Crop Protection AG)

Pesticide Application	Minimum Number of Droplets.cm^{-1}
Insecticides	20-30
Pre-Emergence Herbicides	20-30
Contact Herbicides	30-40
Fungicides	50-70

Considering the values in the table and the results of the drone spraying experiments in hazelnut trees, the droplet densities required for the effective application could not be provided in A and B trials conducted with 10 L ha^{-1} and 20 L ha^{-1} spray norms. The minimum droplet densities required for insecticides, which are the pesticides used most extensively on hazelnut trees at both heights, at 30 L ha^{-1} spray rate, are within the limit values. Although the results obtained from trial C1 performed at the height of 1.5 meters show the most uniform distribution, new studies are needed to determine whether insecticides are effective in these parameters. Tough better droplet densities were observed in the outer and middle regions in trial C2, low densities observed in the leaves in the centre and inner parts raise questions about the efficacy of the insecticides.

4. Conclusions

In line with these findings, the following conclusions can be obtained;

- Low-volume spraying applications are not sufficient to deliver the spray droplets to the inner leaves in hazelnut trees. Spraying trials with higher spray rates need to be performed (4-5-6 L ha^{-1})
- The deposition of the droplets on the inner leaves decreases when the altitude of the drone increases. Uniform droplet distributions were observed at a flight altitude of 1.5 meters.
- To sustain better penetration ability of the droplets, spray applications can be made with larger droplets and at lower flight speeds.

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