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SPRAYING QUALITY USING UNMANNED AERIAL VEHICLE IN CITRUS

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Keywords:
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VMD
Lime

ABSTRACT

This study aimed to evaluate the effect of the operating flight height of an unmanned aerial vehicle with different spray tip rotations on the parameters of droplet coverage, density and volumetric median diameter of the sprayed droplets, in acid lime culture ´Tahiti’. The experiment was performed in randomized blocks design, with repetition within the block, in a factorial system (3x2), with four repetitions. Three planting lines were selected for each treatment. The two outer lines were used as borders and the central one for evaluation. In each treatment, one plant was selected from the planting line and four water-sensitive papers were fixed in the middle third of the outermost portion of the canopy.A solution containing water and a drift reducing adjuvant was prepared to analyze the quality of the spray. A significant difference was found for the variables of spray tip rotation and flight height with no interaction between them. This result indicates that these variables act independently on the volumetric median diameter values. Furthermore, the spray heights of 3.0 m and 4.0 m have a notable effect on the amount of deposition. However, their influence on droplet size is negligible.

Palavras-chve:
Drone
Cobertura de gotas
Densidade de gotas
DMV
Limoeiro

QUALIDADE DA PULVERIZAÇÃO COM VEÍCULO AÉREO NÃO TRIPULADO EM CITROS

RESUMO

Este trabalho teve como objetivo avaliar o efeito da altura de voo operacional de um veículo aéreo não tripulado com diferentes rotações de pontas de pulverização sobre os parâmetros de cobertura, densidade e diâmetro da mediana volumétrica das gotas pulverizadas, em cultivo de limão ´Tahiti’. O experimento foi realizado no delineamento de blocos casualizados, com repetição dentro do bloco, em sistema fatorial (3x2), com quatro repetições. Três linhas de plantio foram selecionadas para cada tratamento. As duas linhas externas foram utilizadas como bordadura e a central para avaliação. Em cada tratamento, uma planta foi selecionada da linha de plantio e quatro papéis hidrossensíveis foram fixados no terço médio da porção mais externa do dossel. Uma solução contendo água e um adjuvante redutor de deriva foi preparada para analisar a qualidade da calda. Foi encontrada diferença significativa para as variáveis de rotação da ponta de pulverização e altura de voo sem interação entre elas. Esse resultado indica que essas variáveis atuam independentemente nos valores do diâmetro mediano volumétrico. Além disso, as alturas de pulverização de 3,0 me 4,0 m têm um efeito notável na quantidade de deposição. No entanto, sua influência no tamanho das gotas é insignificante.

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INTRODUCTION

The genus Citrus has several economically important fruits that are cultivated worldwide for their high nutritional value (HAO, 2019). In Brazil, Citrus are amongst the main cultivated fruit trees (KIST *et al*., 2018). They present great value for the country's economy, promoting socioeconomic growth and generating numerous direct and indirect jobs (NEVES & TROMBIN, 2017).

The main types of citrus grown in Brazil are oranges, tangerines, acid limes, and lemons. Within the genus, the acid lime (*Citrus latifolia* Tanaka), popularly known as Tahiti lime, has been arousing interest for the expansion of commercial plantations. Brazil has an outstanding production of the fruit, with 92% of its production destined for the domestic market, as fresh fruit, mainly due to its availability throughout the year and good appearance (KIST *et al.*, 2017).

Despite the high production of the 'Tahiti' acid lime, there are many challenges in Brazilian citriculture. The most prominent challenge is the phytosanitary problem, causing the reduction of productivity, decrease of citrus fruits quality, and increase in the cost of production (ALMEIDA *et al*., 2018). Currently, chemical spraying is considered the most effective method for prevention and control of pests and diseases (LAN & CHEN, 2018) and can be performed manually or mechanically, through ground or aerial spraying (QIN *et al*., 2016).

According to Tang *et al*. (2018), the use of unmanned aerial vehicles (UAV) for plant protection has increased in recent years, due to the ease of operation in areas of difficult access. In addition, UAV spraying can reduce input costs by up to 80%, optimizing resources and applying pesticides at the appropriate time and place, providing lower environmental impacts compared to other spraying methods (ANDRADE *et al*., 2018). However, the spraying performance and operational parameters of unmanned aerial vehicles should be evaluated in order to elucidate the effects on the distribution of sprayed droplets and to achieve the expected efficiency (MENG *et al*., 2020).

Qin *et al*. (2018) evidenced that spray height influences droplet distribution in wheat. Trials conducted by Lou *et al*. (2018) reported that uniformity, coverage rate, and droplet deposition varied as a function of flight height in cotton. Tang *et al*. (2018) evaluating the effects of operating height and citrus canopy shape demonstrated that at 1.2 meters from the citrus canopy there was better spray performance. Chen *et al*. (2020) demonstrated that for rice crops, the deposition distribution and droplet penetration were influenced by droplet size (CABRAL & VITÓRIA, 2022).

There is little research done on aerial spraying and the ideal operational parameters for citrus trees under Brazilian conditions. Therefore, the objective of this work was to evaluate the effect of the operation height of an unmanned aerial vehicle with different nozzle rotations on the parameters of coverage rate, droplet density and the volumetric median diameter of the sprayed droplets, in the cultivation of the 'Tahiti' acid lime.

MATERIAL AND METHODS

The experiment was conducted in November 2020, at Bello Fruit company farm, Fazenda Rio Preto, located in São Mateus - Espírito Santo (18°49'34.1"S / 39°54'11.2"W), Brazil. According to the Köppen classification, the region's climate is considered hot and humid, type Aw, with a rainy summer season and a dry winter season (ALVARES *et al*., 2013). The experimental area is a Tahiti lime plantation grafted on the trifoliata 'Flying Dragon' with a spacing of 6.0 m between rows and 2.0 m between plants, and age of 7 years. In the experiment, the planting rows containing trees of 2.5 m in height were selected.

The experiment was performed in randomized blocks design, with repetition within the block, in a factorial system (3x2), with four repetitions. Three flight operational heights in relation to the lime tree canopy (2.0 m; 3.0 m; and 4.0 m) and two spray nozzle rotations (7,500 rpm and 10,500 rpm) were used. The overflight of the UAV was 60.0 m with the direction aligned in the center of the citrus canopy.

The UAV (Joyance®, model JT-5) used in the experiment had a tank capacity of five liters and flight autonomy of 10 to 25 minutes. The drone had six rotors and two centrifugal spray nozzles.

The UAV could flight to 12 m s^{-1} and its operation speed was from 0 to 8 m.s^{-1}.

Three planting rows were selected for each treatment in order to minimize experimental errors due to spray drift. The two outer rows were used as borders and the central one was used for evaluation.

In each treatment, one plant was selected from the planting line, and four water-sensitive papers (76×26 mm) were attached to the middle third of the outermost portion of the crown, two in the direction of the row and two between the planting line.

The quality of the spray was analyzed using a solution containing water and drift-reducing adjuvant (Helper Air©) prepared with a spray volume of 10 L.ha^{-1}. The flight speed was 6 m.s^{-1}. Nozzle rotation was measured with optical digital tachometer (Akrom Kr98©, model laser-sighted).

The applications were performed according to the methodology described by ISO 22866 (INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, 2005). Therefore, the temperature should be between 5 °C and 35 °C, the wind speed should have a maximum of 10% of the measurements below 1.0 m.s^{-1} and the wind directionshould be within a limit of 90° ± 30° in relation to the spraying line (Table 1). Thus, the ideal wind direction for applications should be east-southeast (112.5°) and may be between east and southeast (90° and 135°). During the experiment, the environmental conditions were monitored using a portable digital anemometer (Instrutherm, model AD-250©) and a digital thermo-hygrometer (Instrutemp, model SH-122©).

The DropScope Wireless©, a water sensitive paper reader, was used. It is composed of a software, a web area for viewing and sharing analyses, and a wireless digital microscope with a digital image sensor with over 2500 dpi. After each treatment and label drying, the impacts on each water sensitive paper label were quantified and characterized. The following parameters were evaluated: volumetric median diameter (VMD, µm), droplet density (droplets.cm^{-2}) and coverage rate (%).

The Levene and Shapiro-Wilk tests were applied to verify the homogeneity and normality of the residues. Data were transformed when necessary and variance analysis was performed. The Tukey's test was applied to identify the difference between treatments, when appropriate. All tests were performed with the Statistical Analysis System Software (SAS 9.1), considering a 5% significance level.

RESULTS AND DISCUSSION

The effects of operational flight height at two spray nozzles rotation levels on application coverage are shown in Table 2. At 10,500 rpm, no statistical difference in the coverage rate as a function of height was found. This result may have occurred because the higher the rotation, the greater the number of droplet fragmentation and, consequently, the greater their coverage on the

Table 1. Climatic conditions at the time of spraying

		Temperature (ºC)		Relative humidity (%)		Wind speed (m s^{-1})	
Date of application	Flight height (m)	Min	Max	Min	Max	Min	Max
09/01/2020	2.0	21.7	25.0	62	67	1.1	1.9
	3.0	21.2	24.9	64	67	1.1	2.2
	4.0	21.5	24.8	63	66	1.0	2.1
09/08/2020	2.0	22.3	25.1	62	65	0.8	1.5
	3.0	22.5	25.0	61	65	1.0	1.7
	4.0	22.6	25.0	61	65	0.9	1.7
09/14/2020	2.0	22.3	23.5	68	72	1.5	1.7
	3.0	22.5	23.4	71	74	1.3	1.5
	4.0	23.1	24.0	68	72	1.5	2.0
09/28/2020	2.0	20.7	21.5	70	74	1.8	2.1
	3.0	20.8	21.7	69	73	1.6	2.5
	4.0	20.9	22.0	68	71	2.0	2.2

target, as described by Matthews (1984).

In most cases, the spray volume applied by UAV is very low (QIN *et al*., 2016; WANG *et al*., 2019), which requires droplet size reduction to optimize crop coverage. However, different droplet sizes can be obtained by changing the rotation of the centrifugal nozzles (QINGQING *et al*., 2017; RHIND, 2000).

For 7,500 rpm, the flight height of four meters showed greater target coverage. Although lower rotations produce larger droplets and, consequently, less coverage. This treatment shows that the higher height leads to a greater range of spray and, thus, more drops to cover the target due to the downwash effect (ZHANG *et al*., 2021). Xue *et al*. (2014) evidenced similar result in their study. Tang *et al*. (2018) concluded that the spray extension is narrower at low operating heights, thus providing less deposition and coverage of the droplets on the target.

Ideal coverage of droplets in spraying differs according to the type of target to be reached. For insect control, due to greater movement and small number of targets, large drops are recommended (BAESSO *et al*., 2014). Products that need good coverage, such as protective fungicides, require finer droplets to obtain effective control (CUNHA *et al.,* 2006). According to Contiero *et al.* (2018), systemic products can be applied in larger droplets, since they are less affected by drift, and ensure target control.

The F test values and the coefficient of variation of the droplet density parameter are presented in Table 2. Most of the variation sources showed no significant differences, except for rotation. This result indicates that the spray nozzles rotation influences the droplet density parameters.

The operating parameters showed no interaction. Therefore, the spray nozzles rotation did not vary with the different flight heights (Table 3).

When analyzing spray nozzles rotation as a function of droplet density, we observed that the rotation of 10,500 rpm provided higher values (Figure 1A). This result indicates that the higher the rotation, the greater the fragmentation of droplets and the greater the number of droplets per area. The results of droplet density found are consolidated by Matthews *et al*. (2016), which pointed out a reduction in droplet density in applications with coarser droplets.

Table 2. Effects of operational flight height subjected to two levels of spray nozzles rotation on the coverage parameter

		Spray nozzles rotation (rpm)	
	Flight Height (m)	7,500	10,500
Coverage (%)	2.0	0.3825 bB	1.2050 aA
	3.0	0.2875 bB	1.0425 aA
	4.0	1.0875 aA	0.7025 aA
	CV = 44.56 %	F interaction = 7.53*	

Means followed by the same lower-case letter in the row and means with upper-case letters in the column do not differ statistically by the Tukey test at 5% significance level

Table 3. Values and significances of F-tests and experimental coefficient of variation (in percentage), based on the average of treatments for the droplet density variable

Droplet density (droplet.cm^{-2})		
SV	DF	F
Block	3	0.7546^{ns}
Spray Nozzles Rotation	1	8.1248*
Flight Height	2	2.6059^{ns}
Interaction	2	0.4405^{ns}
Residue	15	
CV = 29.79 %		

ns = Not significant at the 5% probability level by the F test; and *= significant at the 5% probability level by the F test

The droplet density parameter was not statistically influenced by flight height (Figure 1B). Nevertheless, trials conducted by Tang *et al.* (2018) found differences between droplet density and flight height. Spray performance at an operating height of 1.2 m was better than at other heights evaluated for lime crop. Studies by Lou *et al.* (2018) found interaction of flight height with droplet density for the cotton crop. Qin *et al.* (2018) also found that flight height influenced droplet density.

This influence leads to less droplet drift, but poor droplet deposition. This fact occurs mainly because the leaves, especially within the upper canopy, are influenced by the powerful downward wind, which makes it difficult for the droplets to adhere.

This investigation showed statistical differences for flight height below 4 m. Therefore, further studies should be conducted to evaluate the influence of flight height at lower levels, seeking expressive results in droplet density for lime crops.

Evaluating only the droplet density can determine the best quantity of droplets per area that would be appropriate for each application. However, the volumetric median diameter (VMD) is another crucial factor when defining which spray is more appropriate. Therefore, it should not be used alone as a requirement in the evaluation of agrochemical application (MEWES *et al.*, 2013).

The F test values and significance, beyond the coefficient of variation (in percentage) of VMD in the analysis of variance are presented in Table 4. A significant difference for the spray nozzles rotation and flight height variables was found with no interaction between them. This result indicates that these variables act independently on the values of volumetric median diameter.

In Figure 2 we can observe the volumetric median diameter averages variation for the different spray nozzles rotation and flight heights. We verified a greater VMD for the rotation of 7,500 rpm when compared with the rotation of 10,500 rpm. This result indicates that the lower the spray nozzles rotation, the greater the VMD.

In Figure 2B we can note a significant difference between the flight heights of two and three meters. The flight height of four meters, in turn, did not differ statistically amongst them. At two meters, the highest VMD value was 301.08 µm.

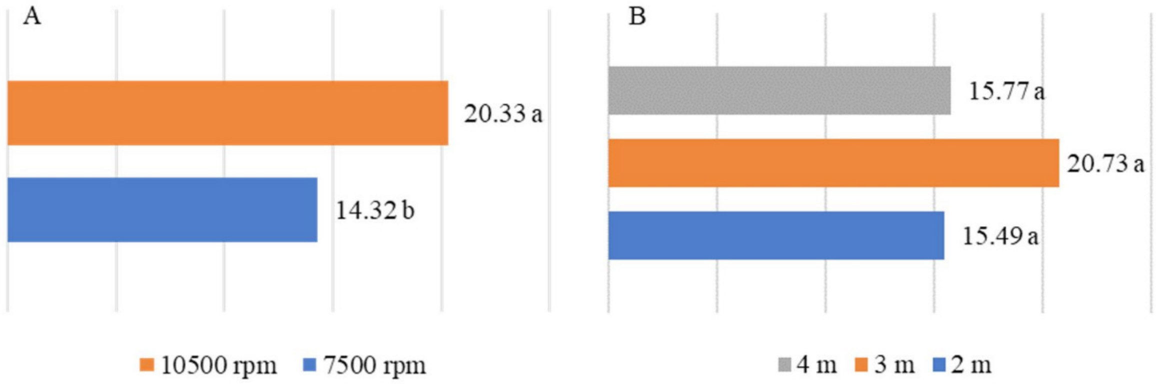

Figure 1. Mean droplet density (droplets.cm^{-2}) variations for rotations of 7,500 and 10,500 rpm (A) and for heights of two, three, and four meters (B)

Table 4. Values and significances of F and the experimental coefficient of variation (in percentage), based on the average of treatments for the volumetric median diameter characteristic (VMD)

VMD		
SV	DF	F
Block	3	1.47^{ns}
Spray Nozzles Rotation	1	56.57*
Flight Height	2	4.37*
Interaction	2	2.08^{ns}
CV = 13.46 %		

VMD = volumetric median diameter; ns = not significant at 5% probability level by F test; and *= significant at 5% probability level by F test

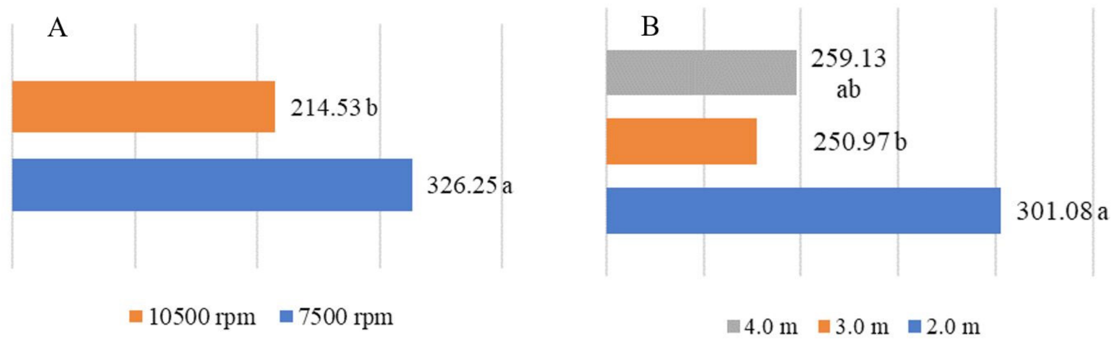

Figure 2. Volumetric median diameter (µm) average variation for the rotations of 7,500 (A) and 10,500 rpm (A) and for the heights of two, three, and four meters (B)

Similar conclusions were reached for operating heights of 3.0 m and 4.0 m. In this sense, it can be inferred that smaller droplets can easily penetrate the canopy and be deposited in the innermost areas of the plant canopy, while larger droplets are deposited on the leaves in the higher and outer layers. However, small droplets tend to be more prone to drift than large droplets, so drift must be controlled (TANG *et al.*, 2018).

Droplet diameter averages were greater than 100.00 µm, indicating environmentally safe spraying, since wider droplets present lower drift risks (ZAMPIROLI *et al.*, 2019). Berna (2017) described that droplets less than 50 µm wide tend to evaporate before reaching the desired target. At times when wind speed is very low (< 3 $km.h^{-1}$), sprayed droplets, especially the finest ones, can be suspended in the air, not reaching the target and being dispersed to outer areas (CONTIERO *et al.*, 2018).

Tang *et al.* (2018) found results that show the same trends in droplet coverage rate and droplet density. It is likely that the proper degree of downwash generated by the rotors will open the canopy and help the particles penetrate deeper into the plant canopy (XUE *et al.*, 2014; XUE *et al.*, 2016; CABRAL & VITÓRIA, 2022).

Each of the 43 different genotypes of lime crops presents different canopy architectures. Ongoing experiments are evaluating other genotypes, different ages of crop development and application rates best suited for each combination of these variables, as well as verifying the effectiveness of pesticides applied by unmanned aerial vehicles.

CONCLUSION

- Higher rotations of the centrifugal spray nozzles increased the coverage rate of the sprayed droplets for flight heights of 2.0 m and 3.0 m;
- The droplet density was influenced by spray nozzle rotation and spraying showed high mean VMD.
- The results show that spray heights of 3.0 m and 4.0 m have a notable effect on the amount of deposition, but their influence on droplet size is negligible.

AUTHORSHIP CONTRIBUTION STATEMENT

NASCIMENTO, V.P.: Conceptualization, Formal Analysis, Resources, Visualization, Writing – original draft; **VITÓRIA, E.L.:** Conceptualization, Formal Analysis, Methodology, Supervision, Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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