Influence of application rate and flight orientation on droplet deposition by remotely piloted aircraft (RPA) in 'Gala' apple orchards

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Abstract.

Apple cultivation is one of the main sectors of Brazilian fruit production, with the 'Gala' cultivar accounting for approximately 57% of national production. However, its high susceptibility to diseases requires efficient phytosanitary management strategies capable of ensuring adequate canopy protection, especially during flowering. In this context, aerial spraying using remotely piloted aircraft (RPA) has emerged as a promising alternative to optimize phytosanitary applications, reduce spray drift, and improve operational safety. Therefore, this study aimed to evaluate droplet deposition in different canopy strata of apple trees during flowering, assessing the effects of flight orientation and application rate on spray quality. The experiment was conducted in southern Brazil using a DJI Agras T50 RPA. Treatments were arranged in a factorial design combining three application rates (80, 100, and 120 L ha⁻¹) and two flight orientations (parallel and perpendicular to orchard rows). Operational parameters were standardized at a flight speed of 10 km h⁻¹, operating height of 2.5 m above the canopy, spray swath width of 6.9 m, and fine droplets (150 µm). Droplet density and leaf coverage were evaluated in the upper, middle, and lower canopy thirds. Generalized Linear Models (GLM) showed that spray quality responses varied among canopy strata. In the upper third, a significant interaction between application rate and flight orientation was observed. Treatment T6 (120 L ha⁻¹ × perpendicular orientation) resulted in the highest droplet density and leaf coverage values. In the middle and lower thirds, the factors acted independently, with application rates of 100 and 120 L ha⁻¹ producing superior deposition performance. Perpendicular flight orientation consistently increased droplet penetration and leaf coverage in the inner canopy layers. These results demonstrate that aerial spraying using RPA is an effective strategy for phytosanitary management in 'Gala' apple orchards, contributing to improved canopy protection during flowering.

Keywords.
Malus domestica; remotely piloted aircraft; spray deposition; precision agriculture

Introduction

Apple production is one of the most important sectors of Brazilian fruit farming, with the 'Gala' cultivar accounting for approximately 57% of national production (Faoro et al., 2022). However, this cultivar is highly susceptible to diseases, requiring effective application technologies to ensure adequate canopy coverage, particularly during the flowering period (Boneti and Katsurayama, 1999). In this context, precision fruit farming has emerged as an alternative to optimize phytosanitary applications by reducing spray drift and enhancing operator safety. Among these technologies, aerial spraying using remotely piloted aircraft (RPA) has gained increasing attention as a viable strategy for orchard phytosanitary management. Therefore, this study aimed to evaluate spray deposition in the upper, middle, and lower canopy strata of apple trees during flowering, assessing the effects of different flight orientations and application rates.

Material and Methods

The experiment was conducted in Santa Lúcia do Piaí, Rio Grande do Sul, southern Brazil, using a DJI Agras T50 RPA for spray application. The experimental design consisted of a factorial arrangement combining three application rates (80, 100, and 120 L ha^{-1}) and two flight orientations (parallel and perpendicular to the orchard rows), resulting in six treatments: T1 (80 L ha^{-1}, parallel); T2 (100 L ha^{-1}, parallel); T3 (120 L ha^{-1}, parallel); T4 (80 L ha^{-1}, perpendicular); T5 (100 L ha^{-1}, perpendicular); and T6 (120 L ha^{-1}, perpendicular). Operational parameters were standardized across treatments, including a flight speed of 10 km h^{-1}, an operating height of 2.5 m above the canopy, a spray swath width of 6.9 m, and a droplet size setting corresponding to fine droplets (VMD = 150 µm).

After spraying, leaves were collected from the upper, middle, and lower canopy thirds of 15 previously marked trees per treatment. Droplet density (droplets cm^{-2}) was quantified using Dropsight® software (Pessl Instruments, Austria), through image analysis of UV fluorescent tracer deposits retained on leaf surfaces.

Results and Discussion

Deviance analysis based on Generalized Linear Models (GLM) indicated that the effects of the operational parameters varied among canopy strata. In the upper canopy third, a significant interaction between application rate and flight orientation was observed, indicating that the effect of application rate depended on aircraft flight orientation. Treatment T6 (120 L ha^{-1} × perpendicular flight orientation) achieved a droplet density of 159 droplets cm^{-2} and spray coverage of 3.5%, differing significantly only from treatment T1 (80 L ha^{-1} × parallel flight orientation) (Figure 1).

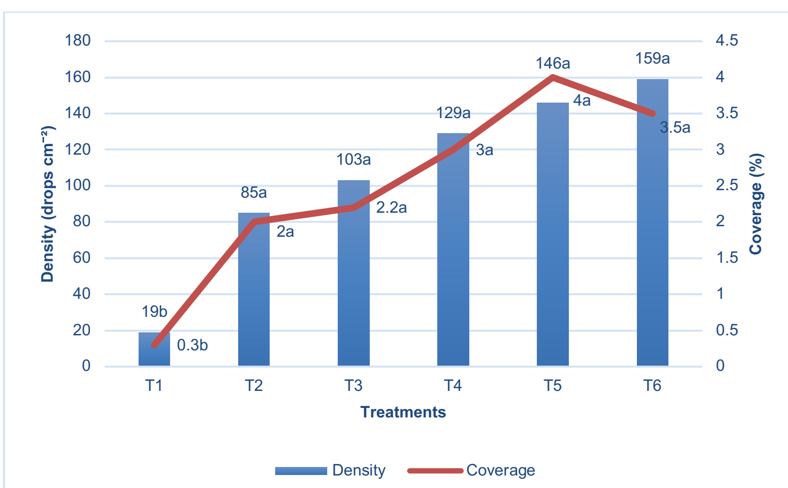

Fig. 1 Effect of the interaction between application rate and flight orientation on deposition in the upper third of apple trees

Unlike the upper canopy third, application rate and flight orientation exerted independent significant effects in the middle and lower canopy strata, corroborating the findings reported by

Wang et al. (2022). In both strata, the 120 and 100 L ha^{-1} application rates did not differ significantly and produced the highest droplet density and leaf coverage values. In the middle canopy third, these rates resulted in droplet densities of 154 and 112 droplets cm^{-2} and leaf coverage values of 3.7 and 2.8%, respectively (Table 1).

Table 1. Effect of application rate and flight orientation on droplet density and leaf coverage in the middle third of the canopy.

Factors	Levels	Density (drops cm^{-2})	Coverage (%)
Application Rate (L/ha)	80	50 b	1.0 b
	100	112 a	2.8 a
	120	154 a	3.7 a
Flight Orientations	Parallel	75 b	1.8 b
	Perpendicular	121 a	2.7 a

Means followed by the same letter in the columns do not differ statistically (Tukey, $p < 0.05$).

Similarly, in the lower canopy third, the 120 and 100 L ha^{-1} application rates provided the highest droplet density and leaf coverage, reaching 132 and 99 droplets cm^{-2} and 3.0 and 2.3%, respectively (Table 2). Flight orientation also significantly affected the evaluated variables, with the perpendicular orientation promoting higher droplet density and greater leaf coverage in the middle and lower canopy thirds. Moreover, the combination of higher application rates and perpendicular flight orientation improved spray penetration and deposition within the canopy. During the early phenological stages, the relatively open canopy structure of apple trees facilitates droplet penetration into the inner canopy layers (Xun et al. 2022). Under these conditions, the interaction between flight orientation and application rate plays a critical role in achieving foliar coverage levels required for effective disease management.

Table 2. Effect of application rate and flight orientation on droplet density and leaf coverage in the lower third of the canopy.

Factors	Levels	Density (drops cm^{-2})	Coverage (%)
Application Rate (L/ha)	80	58 b	1.2 b
	100	99 a	2.3 a
	120	132 a	3.0 a
Flight Orientations	Parallel	59 b	1.3 b
	Perpendicular	139 a	3.1 a

Means followed by the same letter in the columns do not differ statistically (Tukey, $p < 0.05$).

Conclusion

At the beginning of the crop cycle, the high porosity of the canopy facilitates droplet penetration, allowing operational factors to independently influence spray quality. At this stage, application technology plays a strategic role in protecting young tissues by providing droplet densities sufficient to ensure the efficacy of contact fungicides.

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