

## UAV-based automation: a case study of coffee crop input application in Caconde, Brazil

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### Abstract

Precision agriculture optimizes agricultural practices by applying inputs at the right time and place, enhancing productivity and sustainability. This study compared the costs, time requirements, and water efficiency of using an unmanned aerial vehicle (UAV) versus the traditional manual backpack sprayer method on a 5-hectare coffee farm in Caconde, São Paulo, Brazil. Results showed that UAV application reduced operational costs by 21.8% (R\$750 vs. R\$960), water consumption by 96% (50 liters vs. 1,250 liters), and application time by 75% (two hours vs. eight hours). Sensitivity analysis confirmed the cost-effectiveness of UAV method under varying labor costs. This study underscores the economic and environmental advantages of UAV spraying and highlights its potential to address labor shortages and promote sustainable precision farming.

**Keywords:** Precision farming; UAVs; DJI AGRAS T25; Coffee farming; Sustainability.

### 1. Introduction

Precision agriculture can be summarized by the three Rs: the right time, the right amount, and the right place. It involves using advanced technologies and practices to manage spatial and temporal variations related to agricultural production. The main goal is to improve crop performance and environmental quality (Pierce; Nowak, 1999).

Unmanned aerial vehicles (UAVs), also known as drones, are aircraft controlled via radio that fly without a human pilot. They have been widely used in precision agriculture.

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UAVs can provide high-resolution aerial imagery and real-time data for multispectral mapping and crop monitoring. Additionally, UAVs can spray fertilizers or pesticides and assist in seeding (Guebsi et al., 2024).

UAVs can operate effectively in steep areas without being obstructed by obstacles. Compared to ground spraying techniques, they separate the tank from the operator, making them safer alternatives to traditional backpack sprayers. In addition, they help reduce operational costs by shortening the time required for spray applications and minimizing the amount of water and input products used. One disadvantage of this method is the potential risk of environmental drift (Garre; Harish, 2018; Sahni et al., 2024).

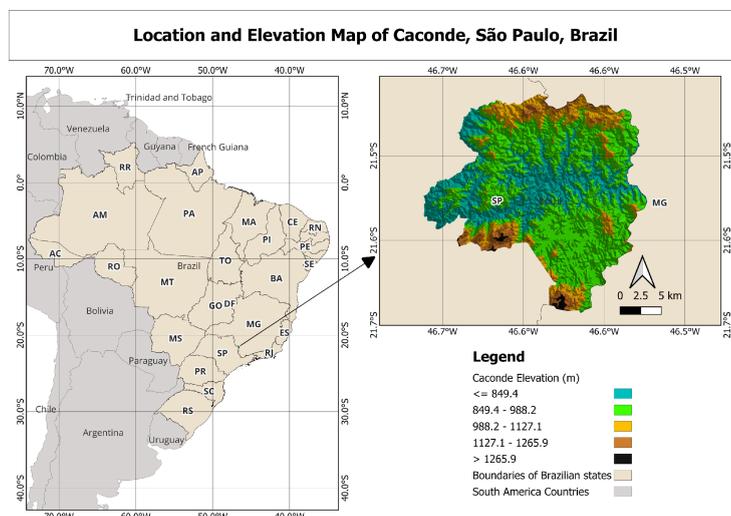
The favorable relationship between altitude and fruit quality has led to the production of coffee in mountainous regions of Brazil (Simão, 2021). One good example is the municipality of Caconde, a significant coffee producer in São Paulo state. With an average elevation of 812 meters, in 2023, Caconde produced 13,500 tons of coffee (IBGE, 2025).

Due to the mountainous terrain, rural producers in Caconde face significant challenges when it comes to using machinery and securing labor for applying inputs. Operating backpack sprayers in these conditions is particularly strenuous, which makes it difficult to attract and retain workers for the job.

In response to labor shortages and limitations in machinery, coffee producers in Caconde have turned to using UAVs to spray biological inputs. This case study evaluates the effectiveness of this method on a small coffee farm in Caconde, Brazil, by comparing and quantifying its cost efficiency, time efficiency, and water conservation with the traditional manual backpack spraying method.

## 2. Methods

Situated on the border of São Paulo and Minas Gerais, Caconde encompasses 468.2 km<sup>2</sup>. Located at a latitude of 21°31'71"S and a longitude of 46°38'69"W, the municipality has a significant elevation range of 708 to 1,388 meters, with an average elevation of 848 meters (Figure 1).



**Figure 1.** Location and elevation map of Caconde, São Paulo, Brazil.

Data on operational costs, time efficiency, and water usage was collected from a five-hectare coffee farm in Caconde which uses a DJI AGRAS T25 unmanned aerial vehicle (UAV) for automated spraying. These metrics were then compared with those of traditional manual labor using backpack sprayers, as detailed in Table 1. The selected farm is representative of small coffee farms in the Caconde region with steep slopes and limited access to mechanized equipment. It was chosen based on the producer's willingness to participate, and its use of both the UAV and traditional backpack methods in recent crop cycles. While it is not statistically representative of all farms in the region, it provides valuable insights into the operational challenges and advantages of UAV application in typical mountainous conditions.

**Table 1.** Comparison of unmanned aerial vehicle (UAV) and manual labor for input application in coffee farming

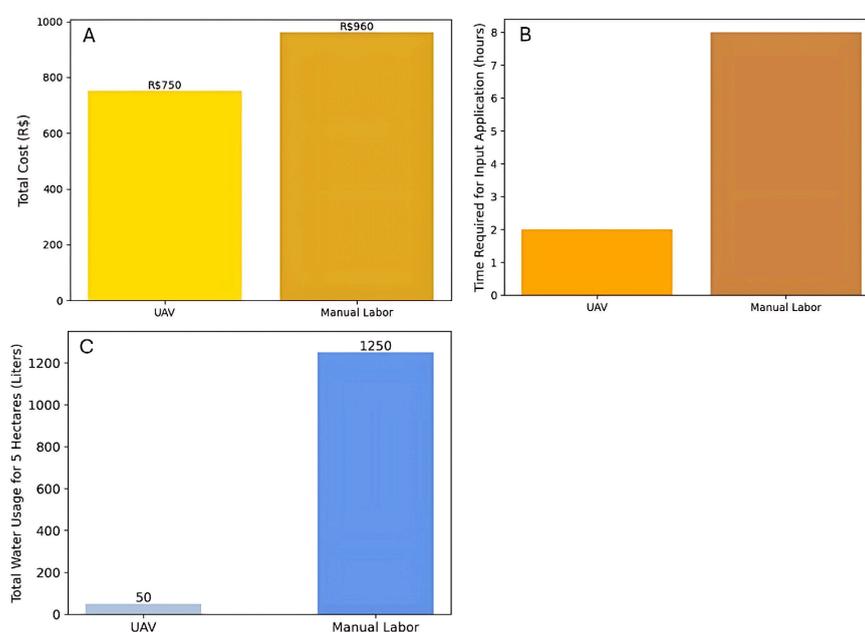
Category	UAV input application	Manual labor input application
Equipment/ workforce	DJI AGRAS T25 UAV	1.6 workers per hectare (8 workers for 5 hectares) using backpack sprayers
Cost	R\$ 150.00 per hectare	R\$ 120.00 per worker
Time required	25 minutes per hectare	1.6 hours per hectare
Water usage	10 liters per hectare	200-300 liters per hectare

We conducted a sensitivity analysis to evaluate the impact of fluctuating costs. We considered UAV application costs ranging from R\$150.00 to R\$200.00 per hectare and manual labor costs ranging from R\$120.00 to R\$180.00 per worker.

### 3. Results and Discussion

#### 3.1 Cost efficiency, water conservation, and time efficiency

The total cost of the UAV application is R\$750.00, while the cost of manual labor is R\$960.00. Using UAV technology results in a 21.8% cost reduction (Figure 2A).



**Figure 2.** Comparison of unmanned aerial vehicle (UAV) applications and manual labor: (A) cost; (B) time required; (C) water usage.

Umeda et al. (2022) examined pest control in Japan and found that using UAV resulted in a 50.04% cost reduction compared to boom sprayers. These results support the potential cost savings of UAV technology and highlight its significant economic benefits in agricultural practices.

The application of UAV technology drastically reduced operation time, completing the task in just 2 hours compared to 8 hours with manual labor. This 6-hour reduction represents a 75% decrease in time, which significantly increases farm productivity (Figure 2B).

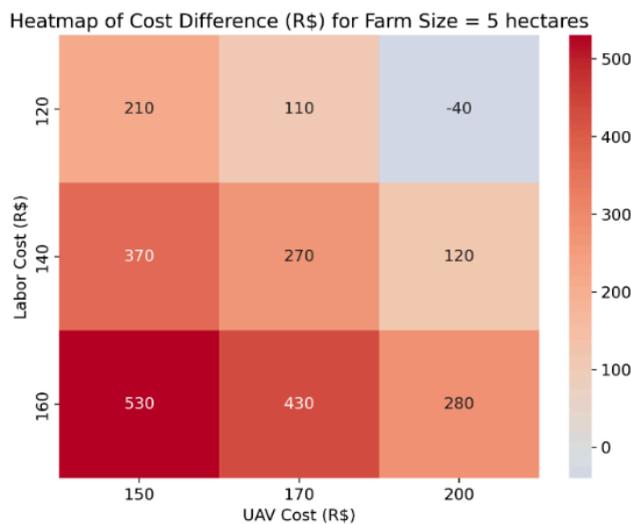
Morales-Rodríguez et al. (2022) highlighted the time efficiency of UAV sprayers. They reported that the least efficient UAV model tested operated at a rate of 4.8 hectares per hour, which is nearly three times higher than the 1.6 hectares per hour achieved by trailed conventional sprayers.

The UAV application used only 50 liters of water across the 5-hectare farm (10 liters per hectare), compared to 1,250 liters used in manual application (averaging 250 liters per hectare). This demonstrates a 96% reduction in water usage and underlines the significant contribution of UAVs to sustainable agricultural practices (Figure 2C).

Garre and Harish (2018) conducted a study to analyze the efficiency of UAV-based pesticide spraying in agriculture. They reported significant variability in water savings, ranging from 20% to 90%. They attributed this variability to factors such as the altitude and weight of the UAV.

### 3.2 Sensitivity analysis

In the scenario where labor costs are R\$120.00 and UAV application costs are R\$200.00 per hectare, the UAV application is R\$40.00 more expensive than manual labor, as reflected by the negative heatmap value. Conversely, when labor costs are R\$160.00 and UAV application costs are R\$150.00 per hectare, the heatmap shows a positive value, demonstrating that UAVs are R\$530.00 cheaper than manual labor in this specific scenario (Figure 3).



**Figure 3.** Heatmap of the cost difference between unmanned aerial vehicle (UAV) application and manual labor.

These cost variations underscore the economic viability of UAV applications in various labor cost scenarios. In addition to direct cost savings, UAVs provide substantial time savings and dramatically reduce water consumption. This contributes to economic and environmental sustainability in the agricultural practices of the five-hectare Caconde coffee farm.

#### 4. Conclusion

This study demonstrates the superiority of using a UAV for precision spraying on a challenging five-hectare mountainous coffee farm in Caconde, São Paulo, Brazil, compared to traditional manual backpack spraying. Using a UAV resulted in significant improvements, including a 21.8% decrease in operating costs, a 96% reduction in water usage, and a 75% increase in spraying speed. These results demonstrate that UAV spraying enables more efficient use of resources and is an eco-friendly practice that supports sustainable coffee production.

While this research points to significant benefits, its findings are limited because they are based on a single case study. Future research should incorporate a larger sample of farms, expand UAV applications to a broader range of crops, and explore integrating UAV technology with other precision agriculture tools.

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