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# Drift reduction in orchards through the use of an autonomous UAV system

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ABSTRACT

The demands of a growing population and a developing global economy will require an increase in agricultural yield of 70% over the next 30 years. However, achieving this goal is only possible with a sustainable intensification of agricultural systems. Spraying drones are one of the available technologies that could help meet this goal. Presently, the use of spraying drones is limited by both the legal framework and the lack of scientific knowledge about the drift they generate compared to conventional terrestrial spraying platforms. However, the flexibility that spraying drones provide, their characteristic vertical spraying, and the downwash airflow produced by the rotors might reduce drift. This study aimed to compare the drift generated by a conventional orchard sprayer to that generated by a spraying drone in a commercial superhigh-density olive orchard. Trials to assess the sedimented drift of both spraying platforms were conducted in the South Iberian Peninsula in 2022. Our results show that the drone sprayer required less than half the distance to sediment 90% of the sprayed volume compared to a conventional mist blower.

## 1. Introduction

Presently, unmanned aerial vehicles (UAVs) are gaining popularity in the agricultural sector due to their versatility, flexibility, and spatial and temporal resolution for gathering data, such as aerial images, from a vantage point. As a result, UAVs are being used for a comprehensive and increasing range of agricultural tasks, such as irrigation scheduling based on thermal information (Egea et al. 2017), pest and disease detection (Jung and Park, 2019), yield estimation (Apolo-Apolo et al. 2020) and spraying plant protection products with a high spatial resolution (Huang et al. 2009).

Some studies suggest that spraying drones has several advantages over conventional spraying systems, especially when compared to backpack sprayers (Wang et al. 2018; Sarri et al. 2019; Xiao et al. 2020). The ability to change the flight speed along the route or even hover over specific points gives this autonomous system the capacity for variable rate application and spot spraying. However, the critical limitation of this technology, especially in Europe, is the strict legal framework.

In some situations, spraying drones might be more suitable than conventional spraying systems because they can spray areas difficult for people or machinery to access, such as hilly plots. Moreover, spraying drones might be the only spraying technology able to operate under specific scenarios, such as muddy plots.

The primary aim of this study is to evaluate whether drone spraying systems have benefits over conventional mist blowers in terms of drift under certain conditions. This study compares the sedimented drift of a spraying drone and a conventional orchard sprayer. Our trials were carried out in a representative commercial superhigh-density olive orchard whose characteristics and agricultural practices are common to orchards of the same type in the Mediterranean region. To our knowledge, this application is new, and it is the first time this comparative study has been done under Mediterranean conditions.

## 2. Materials and methods

### 2.1. Spraying systems

#### 2.1.1. Orchard sprayer

The tractor-mounted mist blower (Zebra Axial 600, HARDI International, Nørre Alslev, DK) was attached to a Claas Elios 240 (Claas, Harsewinkel, DE), 73 kW tractor (Fig. 1). This is the typical type of sprayer used in olive orchards and for woody crops in general. Each side of the mist blower had six ceramic hollow cone nozzles (Albuz ATR-80, Solcera, Evreux, FR). The two bottom nozzles were yellow nozzles, the two middle nozzles were orange, and the top nozzles were red. The top red nozzle of each side of the orchard sprayer was closed to adjust the

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sprayed area to the crop's height. The mist blower operated with the rear intake at 280 rpm and 10 bar, the final application rate was 800 L·ha$^{-1}$.

### 2.1.2. UAV sprayer

The drone spraying system is a prototype hexacopter with an RTK-GNSS system, a 16 L tank, and four green hollow cone nozzles (KZ-80 06, Ningbo Licheng Agricultural Spray Technology Co., Ltd, Yuyao, CN) placed just below the frontal rotors. The application parameters for our equipment were a flight speed of 1.5 m·s$^{-1}$ at 1.5 m above the canopy. With these flight parameters, the final application rate was 45 L·ha$^{-1}$. In addition, we carried out calibration tests for both sprayers. In these tests, we measured the flow of each nozzle under working conditions for 30 s to confirm that the real flow of each nozzle was consistent with the expected flow and to ensure a homogeneous spray on both sides of the mist blower.

## 2.2. Experimental design

The experimental plot and meteorological conditions met the requirements of ISO 22522 (2007) and ISO 22866 (2005). Weather conditions were monitored using three weather stations (Raincrop, Sencrop, Lile, FR; Windcrop, Sencrop, Lille, FR; Froggit WH3000SE PRO, Shenzhen Fine Offset Electronics Co., Ltd, Guangdong, CN). The target area was sprayed three times for each trial and sprayer. The sedimented drift was collected at 1, 2, 3, 5, 7.5, 10, 12.5, 15, 17.5, 20, 25, 30 and 40 m from the spraying area, and three dosimeters were placed at each distance separated by 1.5 m. The dosimeters were strips of 5.5 × 80 cm absorbent paper fixed to metal plates. Dosimeters were collected and replaced after each repetition (Fig. 2). The tracer used was tartrazine, which was sprayed at a concentration of 0.6 g·L$^{-1}$ using the mist blower and 12 g·L$^{-1}$ using the drone sprayer. We took samples from the tanks of the spraying systems to determine the final amount sprayed.

## 2.3. Spray drift

The tartrazine collected by each dosimeter was determined using a spectrophotometer (Cary UV–Vis Compact, Agilent Technologies, Inc., Santa Clara, USA). To make the drift data comparable, we expressed it as % spray drift following the method described in Xue et al., 2014. Then, the sedimented spray drift functions were determined as a function of distance for each sprayer. Next, the regression functions were obtained from the mean values of the set of replicates. Finally, the buffer zones corresponding to the 10%, 5% and 1% spray drift values were calculated based on the total drift collected for each sprayer. The regression function that exhibited the best fit was an exponential function according to the following expression:

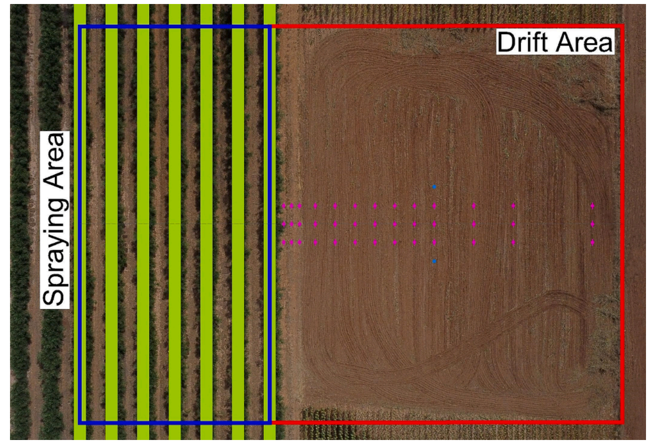


**Fig. 2.** Layout of the experimental site. Sedimented drift dosimeters were placed in the drift area, downwind from the spraying area. Weather stations were placed in the center of the drift area.

$$y = a \cdot Exp^{(-b \cdot x)} \quad (1)$$

where $y$ represents the deposition of the sedimented spray drift (% of spray volume); $a$ is the scale factor; $b$ is the growth rate; and × is the distance from the sprayed area (m).

## 2.4. Data analysis

The effect of the spraying system on the sedimented deposits at each distance was assessed using a one-way analysis of variance (ANOVA). All tests were implemented at a confidence level of 95%. Statistical analysis of the results and the calculation of the buffer zones were carried out using R statistics software (R Core Team 2022).

(a) (b)

**Fig. 1.** A) Typical sprayer currently used by farmers and b) uav-spray application in superhigh-density olive orchard.

## 3. Results and discussion

Sedimented deposition spray drift data (Fig. 3) suggest that the drone sprayer generated significantly less sedimented spray drift than the mist blower. The tested drone sprayer caused less sedimented drift and required less buffer distance than the mist blower. A good fit is observed for the exponential functions fitted from each sprayer's sedimented spray drift values, with $R^2$ values above 0.95 in both cases (Table 1).

The buffer zones were determined based on the fitted exponential functions and establishing a maximum percentage of sedimented spray drift allowed outside the sprayed area of 10%, 5% and 1%.

As Table 2 suggests, the distance required for the established sedimented drift to settle in spraying drones was shorter than the distance required for the conventional mist blower. Using spraying drones over mist blowers can reduce the buffer area required to deposit 90% of the spray drift by a factor of 2.54. Our results indicated that the buffer areas could be reduced by a factor of 2.66 and 2.81 when using a spraying drone as we decreased the sedimented spray drift allowed outside the sprayed area to 5% and 1%, respectively. Substituting conventional orchard sprayers with spraying drones when feasible could significantly reduce the buffer areas as we decrease the sedimented spray drift allowed outside of the sprayed area.

The low volumes that spraying drones can spray limit their use for many plant protection product applications. However, even with this limitation, spraying drones whenever feasible saves a significant amount of surface from the unintentional spraying of plant protection products.

**Table 1**
Parameters of the fitted exponential function for each of the tested sprayers. The general function equation is $y = a{\cdot}Exp^{(-b{\cdot}x)}$ (SE).

| Sprayer | a | b | $R^2$ |
|---|---|---|---|
| Terrestrial | 17.781 (1.438) | 0.296 (0.036) | 0.964 |
| Drone | 22.082 (2.012) | 0.941 (0.073) | 0.986 |

**Table 2**
Distance in meters required downwind from the sprayed area for 90%, 95% and 99% of the sedimented spray drift to deposit for each sprayer.

| Sprayer | 90% | 95% | 99% |
|---|---|---|---|
| Tractor | 8.78 | 11.13 | 16.57 |
| Drone | 3.45 | 4.18 | 5.89 |

As an example, in Spain, the average surface area of commercial olive orchards is 7.38 ha. Therefore, assuming the best-case scenario of perfectly square orchards and that the adoption of spraying drones is more feasible in intensive and superhigh-density olive orchards, the reduction of surface exposed to plant protection products, in which 90% of the sedimented spray drift depositions takes place, would be a minimum of 91,000 ha per treatment. This reduction in diffuse pollution can help increase agricultural systems' environmental and economic

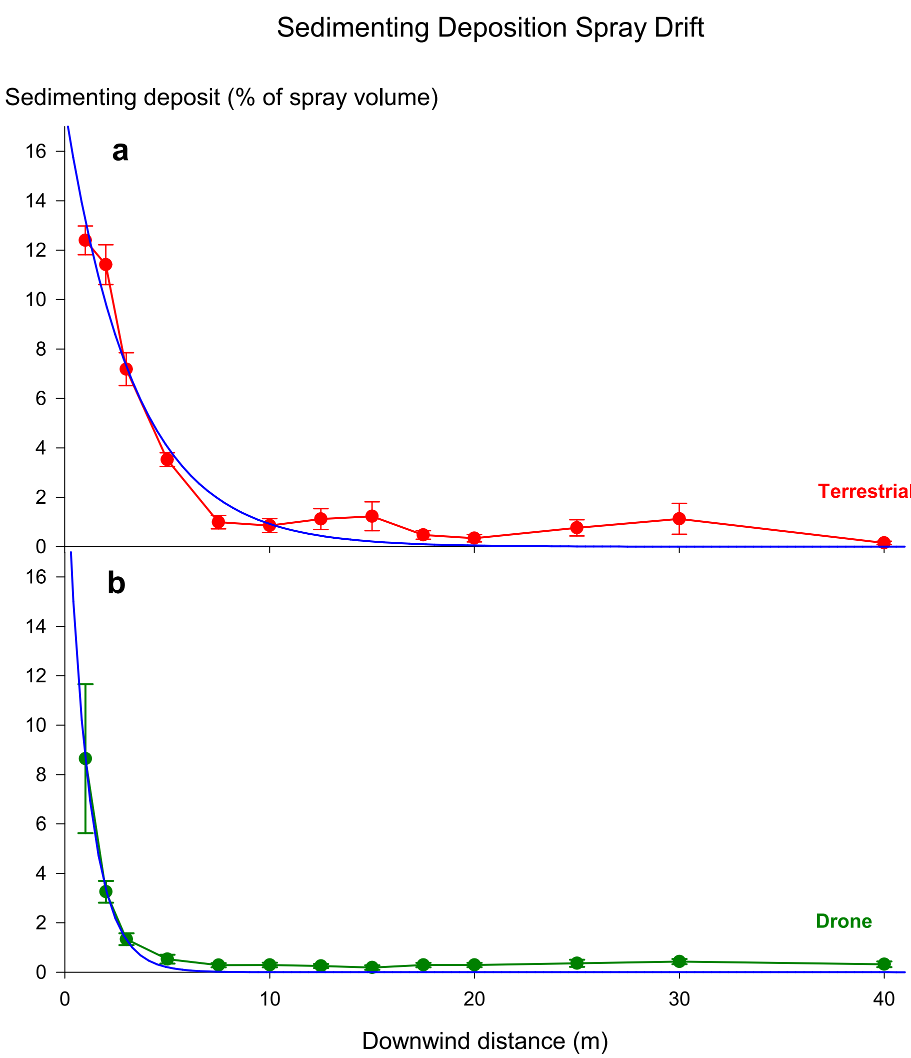


**Fig. 3.** Sedimented depositions (% of spray volume) measured up to 40 m downwind from the sprayed area: *a* Sedimented depositions generated by the mist blower; *b* Sedimented depositions generated by the drone sprayer. Each point represents the average of three spraying events, and bars represent the standard deviation. The fitted exponential functions for each sprayer are shown in blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

sustainability while preserving and expanding vulnerable ecosystems.

## 4. Conclusions

To our knowledge, this is the first study that compares the drift generated by a spraying drone with the drift caused by a mist blower in a superhigh-density olive orchard under Mediterranean conditions. Our study suggests that spraying drone technology might be a powerful tool contributing to the sustainability of Mediterranean agricultural systems. The adoption of this technology is potentially helpful for Mediterranean orchardists that will benefit from the precision and flexibility this technology provides while reducing the environmental impact of plant protection product spraying. Our study shows that, under our conditions, spraying drones generate less sedimented drift than the conventional orchard sprayers typically used, demonstrating their utility under specific scenarios where a high spraying volume is not needed.

## Declaration of Competing Interest

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.

## Data availability

Data will be made available on request.

## Acknowledgements

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