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# Spray deposition assessment using different application techniques in artificial orchard trees

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ABSTRACT

Seven orchard spray application techniques were compared in terms of within-tree deposition quality and off-target losses to the ground and behind the target trees. The studied spray techniques included different sprayer types, fan speeds and air deflector settings. An artificial pear canopy was realized for this purpose. Filter papers and a multiple tracer methodology were used to evaluate deposition. All measurements were conducted indoor and will be used as an input and to validate a CFD orchard spray model.

Results showed that spray application technique has an effect on spray deposition. Sprayer design caused major differences in spray distribution and off-target losses. A sprayer with individual spouts gave the highest deposits on the tree (0.15 L), followed by an axial sprayer (0.10–0.12 L). Changing settings on the axial sprayer only caused minor differences, although the high fan gear performed significantly better than the low gear. Lowest tree depositions were found for a cross-flow sprayer (0.08–0.09 L). A significant portion of the spray liquid was lost to the ground and directly behind the trees with all spray techniques. The axial fan sprayer and the sprayer with individual spouts caused higher ground deposits than the cross-flow sprayer. The cross-flow sprayer on the other hand gave higher losses behind the trees, especially when a high fan speed was applied.



## 1. Introduction

The main goal in all spray applications is to obtain an adequate coverage and uniform pesticide deposition on the target in order to provide sufficient efficacy against the target pest (Gil et al., 2011). Large pesticide losses and unsatisfactory uniformity of distribution may reduce the effectiveness of spraying and increase environmental pollution (Vercruysse et al., 1999). The final amount of pesticide that deposits inside a target tree canopy is influenced by spray physical properties, sprayer design and settings, spray application parameters, tree and orchard characteristics, and weather conditions (Larbi and Salyani, 2012).

The importance of the application technique has been highlighted in several studies. Sprayer design, in general related to the air discharge system, was studied by different authors (Baldoin et al., 2001; Cunningham and Harden, 1999; De Moor et al., 2000; Derksen and Gray, 1995; Holownicki et al., 2000; Pergher et al., 1997; Salyani et al., 2007). Also sprayer operational settings, such as fan speed and air flow rate (Cross et al., 2003; Derksen and Gray, 1995; Pergher and Gubiani, 1995; Pergher and Petris, 2008a; Pezzi and Rondelli, 2000), spray application rate (Balsari et al., 2002; Cross et al., 2001a; Marucco et al., 2008; Pergher and Gubiani, 1995), nozzle positioning and orientation (Derksen and Gray, 1995; Farooq and Landers, 2004; Jaeken et al., 2001), nozzle type and size (Cross et al., 2001b; Derksen et al., 2007; Zhu et al., 2006) and driving speed (Celen et al., 2008; Marucco et al., 2008) are important factors influencing sprayer performance.

Numerous researchers have attempted to understand the complex spray application process via field experiments. These studies are limited by weather conditions, varying crop structures and are time consuming. Moreover, field experiments with different spraying systems cannot be made under directly comparable and repeatable conditions (Nuyttens et al., 2010).

To overcome some of these limitations, some researchers have used artificial canopies as a valuable alternative. Van de Zande et al. (2002) reported research on fan capacity and air outlet settings on

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leaf walls with a defined density composed of artificial leaves and on an artificial apple tree in the laboratory. Jeon et al. (2011) used artificial plants instead of real plants for testing ultrasonic sensors in variable-rate spray applications, because these simulated plants have constant canopy structures during the long duration of the tests. An artificial vineyard was built by Gil et al. (2007) from shade nettings with similar entrapment properties as vines to assess atmospheric loss of pesticides. Codis et al. (2013) developed an artificial vineyard structure for agro-environmental characterization of sprayers and application practices. The structure was composed of collection rows to assess spray deposition on the canopy at different growth stages, and edge rows for reproducing the general characteristics of the canopy and to limit edge effects. Also Catania et al. (2011) constructed an artificial vineyard to investigate the effect of wind on the efficiency of an air-assisted sprayer, because of the constant vegetative characteristics.

The use of an artificial canopy allows researchers to conduct spray experiments in a defined uniform canopy, allowing a substantial reduction of experimental area and the possibility to perform the test indoors under controlled climate conditions. Additionally, for our purposes, the architecture of these trees is easier to characterise and to be used in CFD modelling (Endalew et al., 2010).

The objective of this study was to investigate the effects of spray application technique on spray deposition and distribution on artificial trees, ground deposition and spray losses behind the tree. Results of this research will be used to further develop and validate a CFD orchard spray model (Dekeyser et al., 2013).

## 2. Materials and methods

### 2.1. Spray application techniques

Three trailed, air-assisted orchard sprayers with PTO driven fans were considered in this work: a single axial fan sprayer (Condor V, Hardi, Taastrup, Denmark), a two axial fan cross-flow sprayer (DuoProp, BAB Bamps, Sint-Truiden, Belgium) and a single fan sprayer with individual spouts (Tango, Hardi, Taastrup, Denmark).

The axial fan sprayer and the cross-flow sprayer have the option of changing the fan speed in a high or low setting. Both settings were evaluated as separate application techniques. Additionally for the axial fan sprayer, the angle of the top deflector could be adjusted to the tree height. Two settings were evaluated during the experiments: the optimal deflector setting for a tree height of 3.5 m and a tree row spacing of 3.25 m and the extreme deflector setting in which the top deflector was vertically positioned. The individual spouts of the Tango sprayer were positioned to the best of our ability to cover a tree height of 3.5 m.

In total 7 different spray application techniques were evaluated as given in Table 1. A full description and machine characterization of the 7 spray application techniques, including droplet size distribution, spray liquid and air flow distribution patterns was reported in Dekeyser et al. (2013). Average outlet air velocities and airflow rates ranged from 24.7 m s$^{-1}$ (cross-flow, low fan speed) up to 23.8 m s$^{-1}$ (individual spouts) and from 12,603.9 m$^3$ h$^{-1}$ (individual spouts) up to 50,223.0 m$^3$ h$^{-1}$ (cross-flow, high fan speed).

The sprayers were fitted with Albuz ATR hollow cone nozzles (Saint-Gobain Solcera, Évreux, France). Nozzle size and spray pressure varied depending on the number of nozzles to give a theoretical field application rate of 532 L ha$^{-1}$ of ground surface for an orchard with a tree row spacing of 3.25 m and a two-sided spraying. The sprayer with individual spouts was equipped with 10 Albuz ATR red nozzles at a pressure of 8.0 bar producing a spray with a volume median diameter (VMD) of 177 μm. All other sprayers were equipped with 12 Albuz ATR orange nozzles at 6.0 bar with a VMD of 156 μm (Dekeyser et al., 2013).

Tractor ground speed was set at 6.0 km h$^{-1}$ and PTO speed at 540 rev min$^{-1}$ for all sprayers. Only the right side of the sprayers was examined as the velocity and liquid distribution measurements reported in Dekeyser et al. (2013) only showed minor differences between left and right side. The trees were sprayed one-sided, so only half of the theoretical field application rate was applied. Actual driving speed was calculated for each experiment based on the measured time to spray the track and averaged 5.7 km h$^{-1}$, slightly lower than expected (Table 1). As a consequence, the application rate from the one-sided treatment was increased to 281.0 L ha$^{-1}$ (Table 1). Sprayings were conducted in an experimental hall with dimensions of 36 m in length, 20 m in width and 7 m in height and in the absence of wind. Temperature and relative humidity were recorded during spraying and subsequent drying periods at heights of 1.2 and 2.0 m (Campbell Scientific, Utah, USA) (Table 1). The average values for the three replicates of each spray technique show that all techniques were tested under comparable conditions.

### 2.2. Artificial trees

Five identical artificial, leafed trees (n° 1–5) were used with an inter-row spacing of 3.25 m and an inter-plant spacing of 1.50 m (Fig. 1). The wooden main structure of these trees consisted of a conical trunk with a height of 2.8 m. On the stem, four main branches of 1.0 m length were placed at a height of 0.45 m. Artificial *Ficus benjamina* branches (JPC Import Export, Mont St. Guibert, Belgium) were placed on the main structure to represent a fully leafed classical pear tree (bush-spindle training system) with an average height of 3.25 m resulting in a leaf wall area of about 20,000 m$^2$ ha$^{-1}$ (Pergher and Petris, 2008b). On each tree, 81 branches were distributed containing in total 4455 leaves.

**Table 1**
Overview of the operational settings of the 7 spray application techniques and average speed, application rate and climatological conditions for the three replicates of each technique (average ± SD).

| N° | Sprayer | Nozzle type | Spray pressure (bar) | No. of nozzles | Actual speed (km h$^{-1}$) | Actual application rate (L ha$^{-1}$) | Fan speed | Deflector setting | Average outlet air velocity (m s$^{-1}$)[a] | Airflow rate (m$^3$ h$^{-1}$)[a] | Temperature (°C) | Relative humidity (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Axial | ATR orange | 6.0 | 16 | 5.70 ± 0.02 | 279.9 ± 0.9 | Low | Optimal | 29.0 | 38,615.1 | 21.8 ± 0.2 | 58.4 ± 8.5 |
| 2 | Axial | ATR orange | 6.0 | 16 | 5.68 ± 0.09 | 281.2 ± 4.6 | Low | Extreme | 28.9 | 38,478.4 | 21.7 ± 1.5 | 49.7 ± 8.1 |
| 3 | Axial | ATR orange | 6.0 | 16 | 5.67 ± 0.04 | 281.4 ± 1.8 | High | Optimal | 36.2 | 48,218.6 | 20.9 ± 1.4 | 63.7 ± 7.7 |
| 4 | Axial | ATR orange | 6.0 | 16 | 5.71 ± 0.14 | 279.6 ± 6.6 | High | Extreme | 35.9 | 47,834.6 | 22.1 ± 0.6 | 56.9 ± 12.4 |
| 5 | Cross-flow | ATR orange | 6.0 | 16 | 5.61 ± 0.05 | 284.4 ± 2.5 | Low | N/a | 24.7 | 39,698.1 | 23.3 ± 0.9 | 53.8 ± 11.8 |
| 6 | Cross-flow | ATR orange | 6.0 | 16 | 5.72 ± 0.08 | 278.9 ± 4.1 | High | N/a | 31.2 | 50,223.0 | 23.0 ± 0.2 | 51.6 ± 13.4 |
| 7 | Individual spouts | ATR red | 8.0 | 10 | 5.70 ± 0.06 | 280.2 ± 2.9 | N/a | N/a | 36.8 | 12,603.9 | 22.5 ± 0.5 | 59.2 ± 3.9 |

[a] Dekeyser et al. (2013).