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CFD prototyping of an air-assisted orchard sprayer aimed at drift reduction

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Abstract

The environmental contamination due to off-target deposition of pesticide droplets can be minimized by using optimum design and operating parameters of sprayers. A three-dimensional computational fluid dynamics (CFD) model was developed and used to evaluate concepts of boom sprayer setup to orchard spraying to reduce drift without a decrease in biological efficacy. To track the path of the droplets, a Lagrangian particle tracking multiphase flow model was used, combined with spray atomization models and taking into account the velocity variation at the fan outlet. The studied sprayer settings included: sprayer ground speed, fan speed (air jet velocity), number, type, size, position and orientation of nozzles and liquid pressure. To account for the speed of the tractor, a moving coordinate system was implemented. For the boom sprayer setup, nozzles were employed that produce a flat fan spray pattern (110° Turbo Teejet and 85° Teejet off-centre air induction nozzles). Boom-type spraying was compared to conventional orchard spraying using 80° hollow cone nozzles. There was a good similarity between the vertical spray distribution profile patterns produced from the boom and orchard sprayer setups; however, the boom sprayer setup produced lower droplet concentration to the highest positions and could therefore offer possibilities for drift reduction at long distance, while providing good coverage at a short range. There was a good agreement between measured and predicted vertical spray distribution patterns.

Keywords: Lagrangian model; Turbulent dispersion; Spray atomization; Multiphase flow; Droplet distribution

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1. Introduction

Air-assisted sprayers use air jets to carry pesticide droplets to the target position, to displace the air inside the crop canopy and to assist a uniform deposition of the pesticide droplets on the targeted surface (Walklate et al., 1996; Sidahmed and Brown, 2001; Da Silva et al., 2006; Delele et al., 2005). Numerous studies reported the environmental contamination due to off-target deposition and evaporation of pesticide droplets to the atmosphere (Da Silva et al., 2006; Gil and Sinfort, 2005; Van den Berg et al., 1999). The development of an 'ideal' spraying system, with minimal use of pesticide chemicals and optimal deposit for all of the existing canopies, is very complicated (Gan-Mor et al., 1996).

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For orchard spraying, air assistance is the standard in wet applications. Typically 80° hollow cone nozzles are used. Commonly spraying is done using an air blast axial-flow fans that generate a poorly targeted radial air jet. However, in modern orchard designs cross-flow sprayers are also popular. This sprayer uses an axial-flow fan but can produce a target oriented air jet (Holownicki et al., 2000; Jaeken et al., 2001; Delele et al., 2005). On this type of sprayers, to get the required spray overlap large number of hollow cone nozzles are usually used. However, it is obvious that this overlap could be achieved with lower number of nozzles that have bigger spray angle. Debaer and Jaeken (2006) proposed the use of wide angle (110°) flat fan nozzles that are common to boom sprayers. Preliminary data in demo trials suggest that this setup reduces drift without decreasing the biological efficacy.

The use of modelling is an alternative to the expensive and difficult experimental and field measurements (Walklate, 1992; Weiner and Parkin, 1993; Walklate et al., 1996; Xu et al., 1998; Brown and Sidahmed, 2001; Delele et al., 2005; Da Silva et al., 2006). Walklate (1992) provided a model for the droplet impact and deposition on crops and Walklate et al. (1996) established a model for air jet penetration into crops. Xu et al. (1998) combined the models with a Lagrangian particle tracking method to predict the spray dispersion at different distances from the centre of a radial air-assisted orchard sprayer. There was a reasonable agreement between the measured and predicted normalized fluxes for two different random-walk models for turbulent droplet dispersion (i.e., with and without temporal correlation). Weiner and Parkin (1993) applied a CFD code to model spray trajectories from a mistblower; however, their result was not validated. Brown and Sidahmed (2001) used CFD to evaluate the spray dispersion and deposition from a forestry air blast sprayer; measured and simulated data were generally in good agreement, but there were discrepancies for smaller droplets (24–74 μm). In addition, Tsay et al. (2004) and Molari et al. (2005) used CFD models which were developed with a no canopy condition for evaluating the operating and design parameters of an air-assisted boom and recycling tunnel sprayer, respectively. However, none of these studies were devoted to vertical cross-flow sprayers nor applied the droplet atomization models or investigated different nozzle setups.

The objectives of this research were to develop a CFD model that can predict the droplet dispersion from a cross-flow air-assisted sprayer, taking into account the velocity variation at the fan outlet, the type, position, size and direction of the nozzles and the liquid atomization (sheet break up length and droplet distribution); and to validate the model predictions with measured results. The developed model was used to evaluate the drift reduction concept proposed by Debaer and Jaeken (2006). The effect of the canopy was not taken into account.

2. Materials and methods

2.1. *Air-assisted sprayer*

The modelling was performed for a cross-flow sprayer (BAB Bamps, Belgium). Fig. 1 depicts a cross-flow air-assisted sprayer with two axial-flow fans. The air jet is generated by a PTO-driven double axial-flow fan. The two identical fans have an internal diameter of 0.7 m. The air is forced into the fan and then directed towards the air outlet by internal deflectors. Internal deflectors serve to add a vertical component to the outlet air velocity. The fan outlet has a width of 0.1 m, height 2.64 m, and located at 0.36 m above ground level. The droplets were generated from a series of vertically arranged nozzles. The positions of the nozzles from the axis of the plane jet were 0.13 m. Three different nozzle setups were used (the details are outlined in Section 2.3).

2.2. *CFD model formulation*

The CFD code used for this work was Fluent 6.1.22 (Fluent Inc., Lebanon, USA). The continuous air flow was solved using Reynolds-averaged fluid flow equations. The position of the water droplets (discrete phase) in the continuous air stream was tracked using a Lagrangian particle tracking multiphase flow model.

2.2.1. *Governing equations*

2.2.1.1. Continuous phase. In Cartesian coordinates, for an air flow with a two-way coupling, the Reynolds-averaged fluid flow equations are as follows:

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho u_i}{\partial x_i}=S_{\mathrm{m}} \tag{1}$$