International Conference of Agricultural Engineering
AgEng 2014 Zurich 6–10 July

Ref: C0188

A two dimensional Eulerian-Lagrangian model of spray movement and deposition produced by an air-blast plant protection treatment in a citrus orchard

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Abstract

Field tests to estimate spray drift are currently standardized but are very complex, time consuming, expensive and often cannot be compared. Computational fluid dynamics (CFD) is a useful tool to investigate this phenomenon. The airflow generated by the fan of an air-blast sprayer is highly affected by the canopies, which consequently affects the trajectories of spray droplets and has an important influence on drift. Once determined an air flow model in previous work, the subsequent step is to propose a Eulerian-Lagrangian model to predict droplet trajectories, and compare its results with an experimental mass balance in order to assess its validity. Observed differences between experimental and simulation data have been close to the percentage of spray volume that the mass balance reflected as unknown, thus providing encouraging results.

Keywords: drift, simulation, Computer Fluid Dynamics, pollution, pesticide

1 Introduction

Plant protection products for citrus are mostly applied in Spain using air-blast sprayers. However, part of the spray does not reach the targeted vegetation and drifts, which poses risks to the human health, the environment and increases production costs. It has been estimated that losses to the atmosphere may be at least 12-17% of the total quantity of volume applied (Chueca, Garcerá, Masip & Moltó, 2013).

There is a growing interest in quantifying drift, not only for risk assessment but also for accurately evaluating new methods and devices that can reduce drift. Field tests to estimate spray drift are currently standardized (ISO Standard 22866, 2005), but they are very complex, time consuming, expensive and sometimes results from different experimental sources are impossible to be compared.

Computational fluid dynamics (CFD) makes it possible to represent flows by means of computationally intensive, numerical approximations of the equations that govern fluid motion (Versteeg & Malalasekera, 1995). CFD has demonstrated to be a useful and complementary tool to field tests in order to investigate the phenomenon of drift in treatments with air-blast sprayer (Dekeyser et al., 2013).

The airflow generated by the fan of an airblast sprayer is highly affected by the canopies, which consequently affects the trajectories of spray droplets and has an important influence on drift. CFD models of this interaction has already been investigated in vineyards (Da Silva, Sinfort, Tinet, Pierrat, & Huberson , 2006) or pear trees (Endalew et al., 2010) treatments.

In previous work, a two dimensional CFD simulation of the air flow generated by an air blaster in front of a citrus canopy has been validated with experimental data (Salcedo et al., 2014). This work used a k-ω SST turbulent model and considered the tree canopy as a solid body instead of a porous one, as other authors did for less dense trees. The next logical step consist of simulating the droplets in the air flow and study their trajectories. The present work proposes a Eulerian-Lagrangian model for this purpose. Furthermore, results are compared with deposition and drift experimental data in order to assess the validity of the whole model.

2 Materials and methods

2.1 Proposed model

Figure 1: Geometry of the model

Model domain was 13 m high by 21 m long, simulating 3 rows of trees. First canopy was considered as a solid body and the following canopies were modeled as porous bodies (Figure 1) as described in previous work (Salcedo et al., 2014).

Air velocities generated by the fan were measured from 0 to 1.8 m, every 0.2 m, on a vertical post situated 0.5 m apart of the fan, and on a horizontal post 0.5 m apart. These posts were on a plane lined up with the center of the fan and the tree (plane x=0) and later 30 cm before this plane (plane x=-30), close to the aspiration of the fan. These air velocities were introduced as inlet boundary conditions for the model. Because the tractor needed 0.65 s to move 30 cm, during the simulation we used air velocities of plane x=0 for the first 0.65 s and of plane x=-30 for the next 0.65 s, then the simulation was stopped.

Air was assumed to be a fluid composed of nitrogen, oxygen and water vapor at 300 K. Droplets were considered as liquid water, spherical particles with an initial temperature of 288 K. The diameter of the droplets was 3.10 x10^{-4} m. The simulation consisted in launching 1,500 droplets from the air inlets, taking into account the angle of the nozzles. Initial velocity was determined from the nozzles' diameter and their nominal flow. (Figure 2).

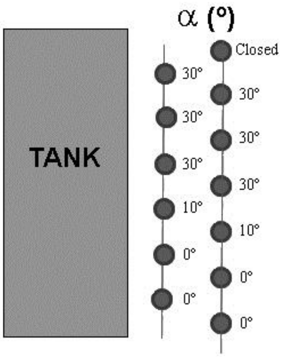

Figure 2: Inclination angle (º) of each nozzle, referred to the horizontal.

A SST k-ω turbulent model (Menter, 1993) reported as having an excellent behaviour on separated flow due to obstacles was used. Turbulence intensity (%) was deducted from experimental data. Characteristic length was 0.14 m m, which represented 5% of air inlet length as reported by Delele et al. (2005).

Simulations were iterative processes that converged to a minimum residual normalized scale of 10^{-4} using ANSYS Fluent 12.0 (ANSYS, Inc. Canonsburg, PA, USA). The numerical scheme was second order in space and time and the SIMPLE algorithm (Ferziger & Peric, 2001) was used.

Results were compared with an experimental mass balance, which estimated product deposition, ground losses and atmospheric drift, as described below. Droplets that the model predicted to hit the ground were compared to ground losses. Droplets that remained above 5.0 m were compared to atmospheric drift. Droplets that remained below 5.0 m and above 2.6 m were unassigned, since they were supposed to fall to the ground or to the trees of the next row.Droplets that remained in a rectangular area whose sides were the actual height of the trees (2.6 m) and their actual diameter (3.8 m) were compared to product deposition.

2.2 Experimental mass balance

An experimental mass balance estimated product deposition on the tree, atmospheric drift and losses to the soil. It consisted in locating different collectors around a tractor path during a conventional treatment (Figure 3): blotting paper collectors were placed on the ground to measure losses to soil and inside the canopies to measure deposition. Horizontal nylon collectors at 5.0 m high were used to estimate atmospheric drift.

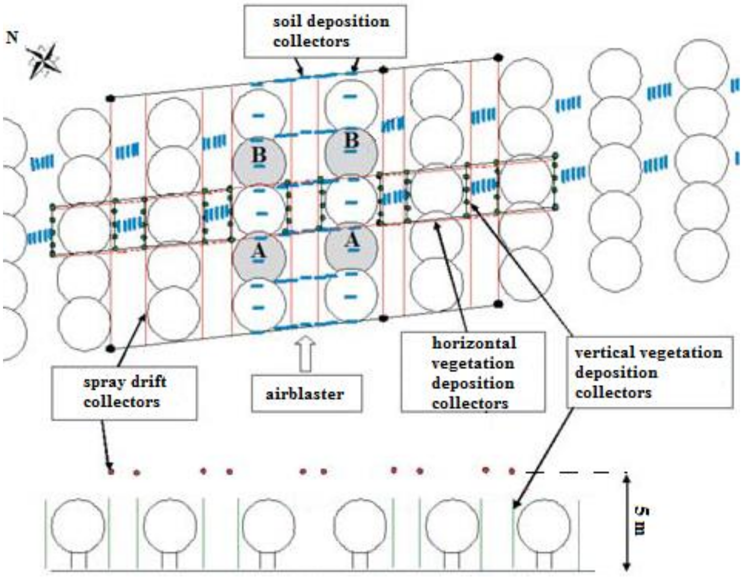

Figure 3: Distribution of collectors during mass balance experiments.

Applications were made with an air-blast sprayer at a tractor speed of 1.65 km/h using conventional cone nozzles (working pressure 1MPa, spray application volume 2930 l/ha) using water and a tracer (Brilliant Sulphoflavine) at 1%.

3 Results and Discussion

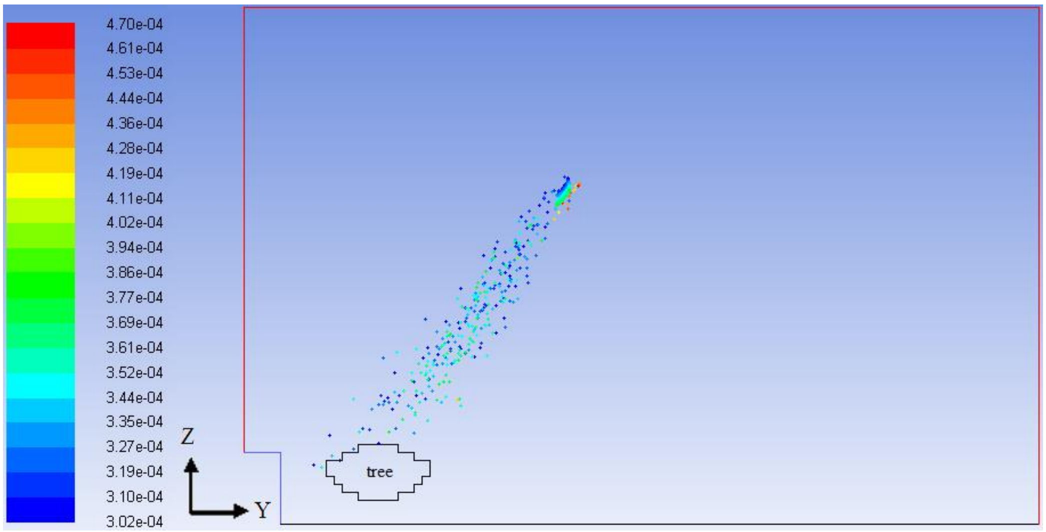

Figure 4: Position of droplets after 1.30 s. Particle traces colored by droplet diameter (m)

The simulation predicted that 548 droplets out of 1,500 (36%) would remain in the air after 1.3 s. These 36% were distributed as follows: 27% were considered as prone to atmospheric drift (those above 5 m) and 9% were unassigned (those below 5 m and above 2,6 m) (Figure 4).The rest of the droplets were trapped either on the ground or in the region corresponding to the first tree. At this moment, simulated particles had a diameter that varied between $3.02\text{x}10^{-4}$ m and $4.70\text{x}10^{-4}$ m. The simulation predicted that none was totally evaporated.
Table 1 compares the experimental mass balance data and the simulation. The former estimated that 40% of the spray volume would deposit on the first canopy, while the simulation predicted 48% deposition. Losses to ground were estimated to be 16%, a value that is very close to 17 % that was predicted by the model. According to the mass balance, 10% of the spray was on the canopy of the trees in the next row, which is a figure close to the unassigned class of droplets in the simulation. Finally, atmospheric drift was 17% in the mass balance against 27% predicted by the model. The mass balance could not determine the fate of 17 % of the spray volume.

Table 1: Comparison between experimental and simulation data

Deposit (%)	Mass balance	Simulation
First canopy	40	48
Losses to ground	16	17
Canopy of the next row	10	n/a
Unassigned droplets (below 5 m and above 2.6 m))	n/a	9
Atmospheric drift (above 5 m)	17	27
Unknown fate	17	n/a

4 Conclusions

Observed differences between experimental and simulation data were close to the percentage of spray volume that the mass balance reflected as unknown, thus providing encouraging results about the numerical representation of what actually happens in field conditions, so this work may represent a first approximation to the simulation of drift in citrus treatments. Future work will develop a more complex, 3D model of this phenomenon.

5 Acknowledgements

This work was partially financed by the Spanish Ministry of Economy (projects AGL2007–66093–C04–01 and AGL2010–22304–C04–01) and the European Regional Development Fund (ERDF). Ramón Salcedo is recipient of a postgraduate FPI-INIA scholarship.

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