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CFD Based Analysis of the Effect of Wind in Orchard Spraying

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The high velocity air jet generated from air assisted orchard sprayers offsets the effect of wind on the spray flow pattern in front of the tree and within the vicinity of the tree height. This combined with the small wind magnitude at lower heights of the boundary layer results in insignificant wind effect within this zone. Once the spray droplets pass through the trees, the velocity of the air jet is significantly reduced by the resistance of the trees increasing the chance of deflection by wind. The projection of the spray droplets also affects the extent of the wind effect and strongly depends on the outlet design of the sprayer. The classical single axial fan sprayer used in this analysis projects part of the spray beyond the tree height resulting in a higher risk of deflection by wind. The CFD modeling approach used in this work allowed studying these wind effects of spray applications in a comprehensive way. It was observed that wind blowing opposite to the spraying direction significantly deflected the spray back to the sprayer. The effect is increased with wind velocity magnitude. Wind blowing in the direction of spraying increased the amount of spray passing through the trees (resulting in increased drift potential), but also increased on-target deposition for this type of sprayer that blows a significant amount of spray over the trees. In this case, wind helps to contain the air assistance of the axial sprayer within the canopy height to some extent.

1. Introduction

The environmental contamination and residues resulting from the use of air assisted orchard sprayers have been a great concern for growers, researchers and policy makers for many years. A wide variety of designs have been developed to improve the sprayer air jet, concentrate the spray particles within the vicinity of the tree zone and recycle some of the spray droplets. There are a lot of other parameters involved in orchard spraying besides the sprayer design including pesticide dose and spray volume (Cross et al. 2001a), spray liquid distribution (Duga et al. 2015), droplet spectrum (Cross et al. 2001b), air volume (Cross et al. 2003), sprayer speed (Celen et al. 2008), meteorological conditions and crop characteristics (Duga et al. 2015). The most important factors that influence risks associated with spray drift are droplet size, pesticide toxicity and meteorological conditions (Praat et al. 2000). A significant number of modelling and experimental works have been done in the past to study the effect of droplet size and pesticide toxicity.
In this work, dedicated Computational Fluid Dynamics (CFD) models, validated using field experiments, were used to study the effect of wind in orchard spraying. Simulations were done using different wind magnitudes and directions. The wind measurements were taken at 10 m height (Table 1). The analysis was done using a classical single axial fan sprayer (CondorV, Hardi, Taastrup, Denmark) operating under different wind conditions and two training systems of pear (Pyrus communis L. cv. Conference): Pear classical (bush-spindle) and Pear T-hedge (hedge of Tienen) and one apple: the vertical axe (Apple classical). The detailed

tree architecture for each training system was integrated in the model to solve the air and spray flow using the Computational Fluid Dynamics code of ANSYS-CFX (ANSYS, Inc., Canonsburg, Pennsylvania, USA).

2. Materials and Methods

Dedicated Computational Fluid Dynamics models were developed for the different combinations of sprayer design and tree architecture using the methodology of Endalew et al. (2010). The wind and the airflow from the sprayers were modelled using the Unsteady Reynolds Averaged Navier-Stokes (URANS) momentum equations and the k-ϵ turbulence model which were solved using the unstructured finite volume method in ANSYS-CFX (ANSYS, Inc., Canonsburg, Pennsylvania, USA). The model tracks the flow and dispersion of the spray droplets using the Lagrangian particle tracking multiphase flow model. The amount of spray deposited on the trees and the amount drifted away was calculated by a stochastic deposition model developed by Endalew et al. (2010). A detailed 3D architecture of the different training systems was used in the model to resolve the resistance and turbulent effects of the solid parts of the tree on the air and spray flow. Source-sink terms were used in a porous domain created around the tree architecture to simulate the momentum and turbulence effects of the plant parts that were not modelled in the canopy architecture.
The simulation domain used for this analysis had a height of 9 m (three times the average height of the trees) to resolve the turbulent boundary layer above the trees. The length and width of the domain varied depending on the planting distance and the tree row spacing (Figure 1). The 3D geometric models of three trees of each training systems were put in a row to represent the actual canopy. The outlet design of the sprayer was represented in the model using a curved cross section. The measured outlet velocity profile of the sprayer was imposed as inlet boundary condition on this cross section to represent the right side of the sprayer. A turbulent intensity of 30 % and a length scale of 0.008 m were used for the turbulence of the sprayer air jet (Delele et al. 2005). A canopy profile was generated iteratively for each of the different wind magnitudes in Table 1 using cyclic simulations and used as inlets on the domain depending on the respective wind directions. A no slip rough wall boundary condition with aerodynamic roughness length (yo = 0.005 m) and an equivalent sand grain roughness height (ks = 0.006 m) was used to represent the ground and the surface of the trees respectively. The remaining boundaries were set as pressure openings. The movement of the sprayer (6 km/h) was simulated using a step function at the outlet cross sections. A series of simulations were done using the wind conditions given in Table 1 and a wind still condition.

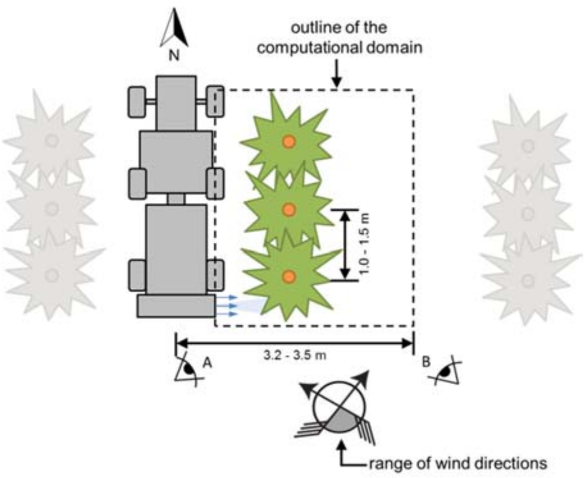

Figure 1. The computational domain and layout of the tree orientation, sprayer driving direction and wind direction. A and B indicate views of the results in Figures 3 to 5

Table 1: The three wind magnitude and directions used for the analysis (based on conditions during deposition trials in the experimental orchard of pcfruit, Sint-Truiden, Belgium); tree rows were oriented South-North

	Wind measured at 10 m height (m s^{-1})		
Sprayer type	Apple classical	Pear classical	Pear T-hedge
CondorV (axial fan)	6.0 (200° South-West)	4.5 (160° South-East)	2.3 (130 South-East)

3. Results and Discussion

Effect of wind on spray flow pattern and deposition

Figures 2a and 2b show the predicted spray flow pattern obtained when the apple classical training system was sprayed with the CondorV sprayer in wind still conditions (Figure 2a) and in the presence of wind (Figure 2b). There was a 6 m/s wind (measured at 10 m height) blowing from 200° South-West, thus almost in the same direction as the sprayer driving direction (South to North, spraying to the East). The particle track plot in Figure 2b was deflected to the North and the deflection is more pronounced than the deflection in Figure 2a. This net deflection was caused by the complex interaction between the wind flow and the sprayer movement. The particle track plot in Figure 2a was slightly deflected to south (opposite to the sprayer driving direction) as expected due to the driving sprayer. Spray contour plots in Figure 3 give the corresponding off-target spray distribution around the trees for wind still operation (Figures 3a and 3c) and operation with South-West wind (Figures 3b and 3d).

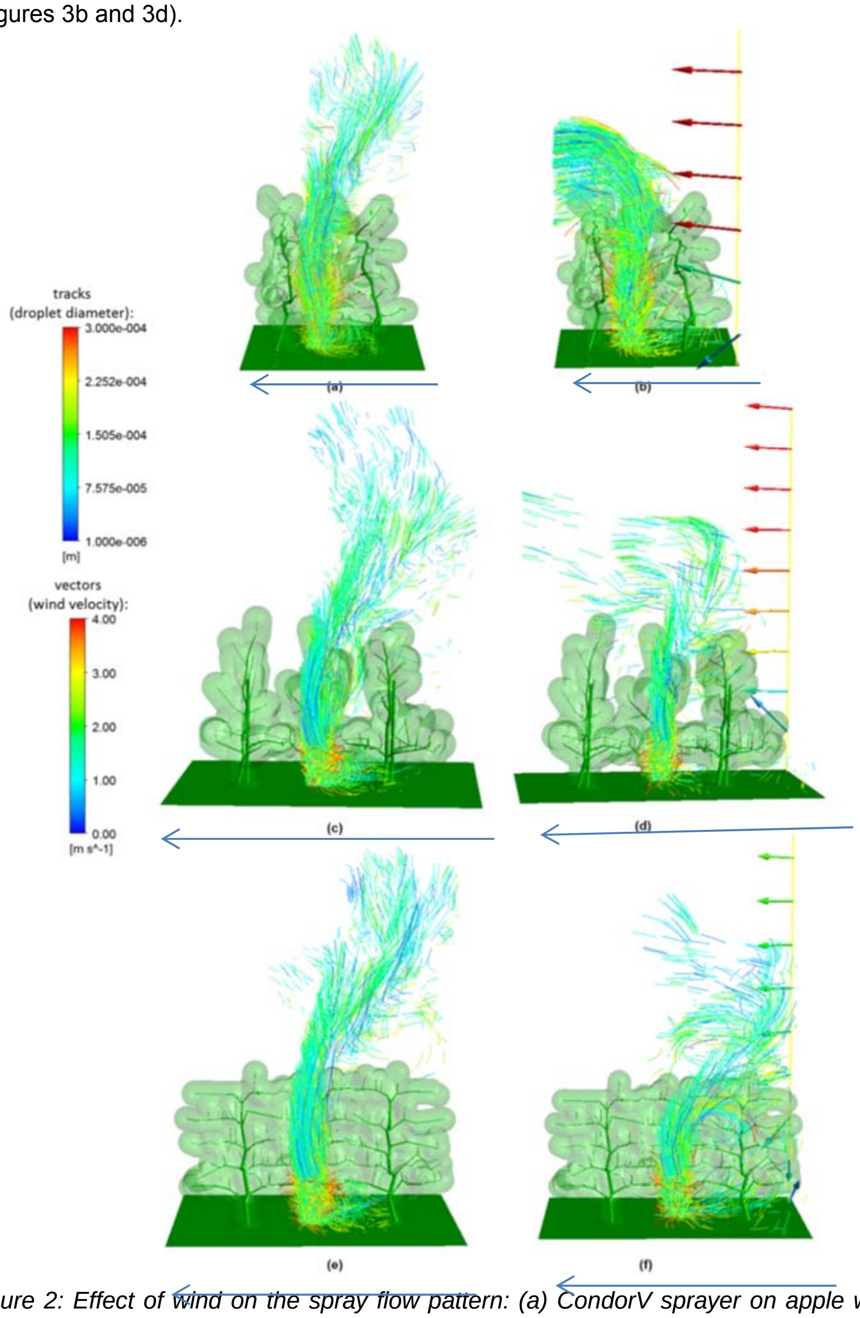

Figure 2: Effect of wind on the spray flow pattern: (a) CondorV sprayer on apple with no wind, (b) CondorV sprayer on apple with a 6 m/s 200° S-W wind, (c) CondorV sprayer on Pear classical with no wind, (d) CondorV sprayer on Pear classical with a 4.5 m/s 160° S-E wind, (e) CondorV on Pear T-hedge with no wind, (f) CondorV on Pear T-hedge with 2.3 m/s 130° S-E wind. The light blue arrows indicate the sprayer driving directions.

Figures 2c and 2d show the effect of a 4.5 m/s, 160° South-East wind on the spray flow pattern obtained when the pear classical training system was sprayed with CondorV, compared to a wind still operation. The sprayer driving direction was again from South to North spraying to the East and wind was blowing opposite to the spraying direction. The spray particles on Figure 2d were deflected back to the sprayer (opposite to the spraying direction) when compared to the no wind condition (Figure 2c). This backward deflection of the spray particles could be seen more clearly by comparing the contour plots in Figure 4. A higher spray amount was detected on the sprayer side compared to the no wind condition.

The particle track plot obtained when the pear T-hedge training system was sprayed with CondorV is shown in Figure 2e and 2f. A 2.3 m/s wind was blowing 130° South-East during this spraying. The magnitude of the wind for this particular case was lower than for the previous two cases. The effect of the sprayer movement on the spray flow pattern was stronger than the prevailing wind. This caused the spray particles to deflect to the South (opposite to the sprayer driving direction) in wind still conditions as well as with opposite wind.

The contour plots on Figures 3, 4 and 5 show the amount of spray deposited on the ground and the amount detected in the air around the sprayer under different wind conditions. Comparing the contour plots in Figure 3a and 3b, a significantly larger amount of spray was detected on a plane in front of the sprayer in Figure 3b, indicating that the spray is taken by the wind along the row. In case of opposite wind, a significant amount of spray is blown onto and over the machine itself (Figure 4d compared to 4c). Important differences are also noted on the ground deposition, which is an interplay of tree architecture, wind and machine characteristics. In the investigated cases, the pear training systems with opposite wind had higher deposition in between the trees, while for the dense apple system with supporting wind there was a significant deposition in front of the tree row.

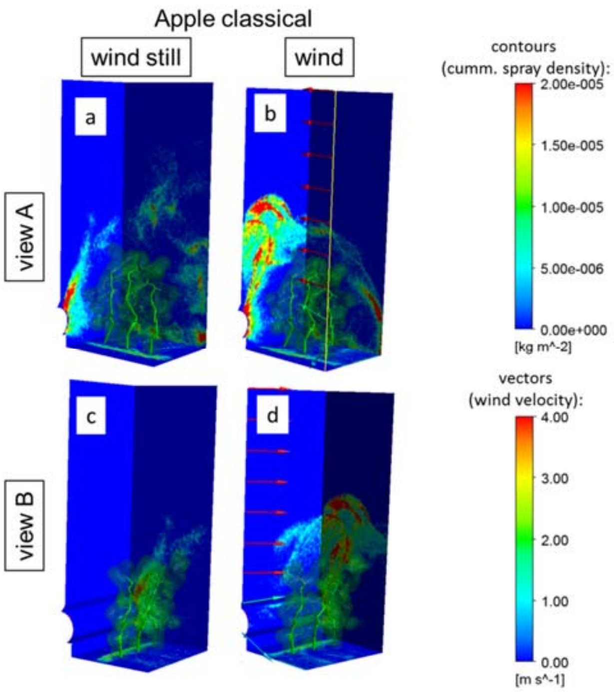

Figure 3. Contour plots showing the effect of wind on the spray distribution in the air around the trees for an apple classical training systems sprayed with CondorV: (a) No wind (View A), (b) With a 6 m/s 200° S-W wind (View A), (c) With no wind (View B), (d) With a 6 m/s 200° S-W wind (View B).(The reference positions of View A and View B are shown in Figure 1).

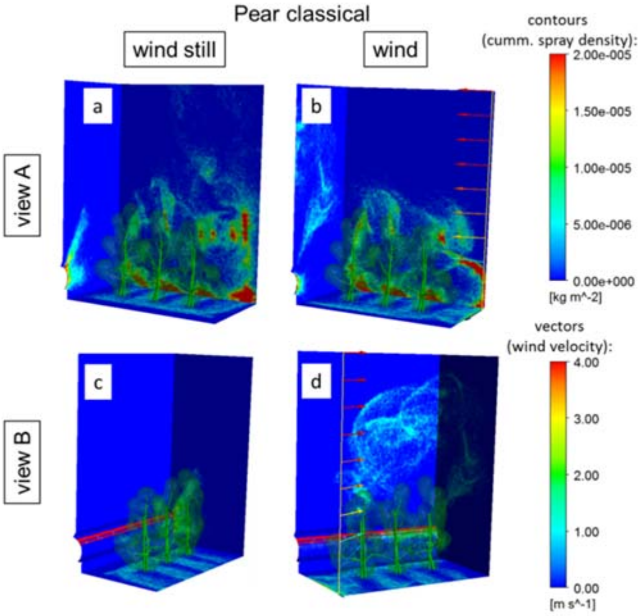

Figure 4. Contour plots showing the effect of wind on the spray distribution in the air around the trees for a pear classical training systems sprayed with CondorV: (a) No wind (View A), (b) With a 4.5 m/s 160° S-E wind (View A), (c) With no wind (View B), (d) With a 4.5 m/s 160° S-E wind (View B). (The reference positions of View A and View B are shown in Figure 1).

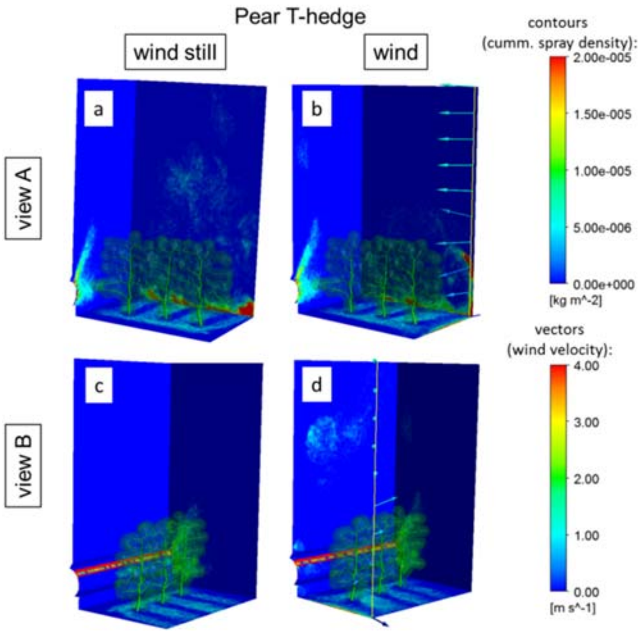

Figure 5. Contour plots showing the effect of wind on the spray distribution in the air around the trees for a pear T-hedge training systems sprayed with CondorV: (a) No wind (View A), (b) With a 2.3 m/s 130° S-E wind (View A), (c) With no wind (View B), (d) With a 2.3 m/s 130° S-E wind (View B). (The reference positions of View A and View B are shown in Figure 1).

4. Conclusions

The magnitude and direction of wind plays a significant role in the flow pattern and deposition of pesticides, even within the orchard. The effect of wind was stronger on the spray droplets at the top of the tree and the droplets that have passed through the trees. The sprayer used for this analysis normally projects a significant amount of the spray further to the top of the trees. The presence of a wind blowing in the direction of spraying could concentrate some of this spray within the tree height. A wind blowing opposite to the spraying direction deflects the spray towards the sprayer resulting in a higher risk of operator contamination.

Acknowledgements

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