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Research Paper

In-situ open path FTIR measurements of the vertical profile of spray drift from air-assisted sprayers

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Estimating pesticide spray drift, which is a part of total drift loss, is complex as airborne pesticide concentrations are low and depend on multiple factors. The aim was to measure and compare vertical profiles of spray drift generated by different sprayers using Open Path Fourier-Transform-Infra-Red (OP-FTIR) spectrometer. Field tests included three types of commercial agricultural sprayers. The OP-FTIR was placed at the edge of an apple orchard with the line of sight parallel to tree rows. The OP-FTIR and its reflector were mounted on platform lifts to allow measurements at 4 heights: 3 (canopy height), 4, 5, and 6 m above ground. The sprayers sprayed water within the three tree rows closest to the OP-FTIR as well as outside each tree row in order to estimate the spray drift as function of distance with and without tree interference. The results of the experiments showed that, under the meteorological conditions prevailing, there were substantial differences between the sprayers in terms of spray drift of droplets with diameter > 5 μm. Additionally, the results showed that spray drift can be reduced substantially (by up to 50%) by using a tree-line barrier or a buffer zone.

1. Introduction

Intensive agriculture, that uses agrochemicals, is essential to address global food demand but also harmful to the environment. Emission of greenhouse gases (e.g. N_2O), ground water contamination and pesticide drift are just a few of the polluting mechanisms associated with modern agriculture. With respect to the latter, the pesticide spray exiting a sprayer starts its trajectory in the form of droplets, which through evaporation may alter in size and chemical concentration (depending on formulation, the pesticide vapour pressure and meteorological conditions). A significant part of sprayed solutions does not reach its intended target (i.e. the leaves or fruit) and it ultimately escapes the target area both during (primary drift) and after application (secondary drift) (Zivan, Segal-Rosenheimer, & Dubowski, 2016).

There are several ways to measure pesticide drift, both offline and in real time. The reviews of Yusà, Coscollà, Mellouki, Pastor, and de la Guardia (2009) and Kosikowska and Biziuk (2010) summarise the methodologies for offline collection of pesticides in the ambient air. Most spray drift measurements have been based on droplets impaction or deposition (Briand, Millet, Bertrand, Clement, & Seux, 2002;

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Nomenclature

$\sum N \cdot L$	cloud column droplet number density (# m^{-2})
A_{op}	telescope diameter (m)
AS	standard air assisted sprayer
C	pesticide concentration in the spraying solution (μl ml^{-1})
D_A	droplet aerodynamic diameter (m)
D_S	droplet spread diameter (m)
E	collection efficiency (%)
FD	fine droplets air assisted sprayer
g	gravitational acceleration (m s^{-2})
$I(\lambda)$	radiation intensity during a spraying event
$I_0(\lambda)$	radiation intensity not during a spraying event
IR	infra-red
L	water droplet cloud length (m)
LIDAR	light detection and ranging
L_{LOS}	length of the line of sight (m)
Load	estimated water load in the line of sight (ml m^{-1} of path)
LOS	line of sight
N_i	droplet number density
NMD	number median diameter (μm)
OP-FTIR	open path Fourier transform infra-red
PUF	polyurethane foam
T	air assisted tower sprayer
V	spray load according to the manufacturer (l)
V_d	average droplets volume (l)
VMD	volume median diameter (μm)
W	WSP width (m)
WSPs	water sensitive papers
$\sigma_{e,i}$	extinction cross section of droplet with diameter i
ρ_a	air density (kg m^{-3})
μ_a	air dynamic viscosity (kg m^{-1} s^{-1})
τ	turbulent intensity (%)
%v	volume percentage
%wt	weight percentage

Longley, Cilgi, Jepson, & Sotherton, 1997). Measurements of airborne pesticides have been mainly obtained by active sampling via filters and absorbing media to capture the particulate and gaseous pesticides (Briand, Bertrand, Seux, & Millet, 2002; Ravier, Haouisee, Clément, Seux, & Briand, 2005). Zivan, Bohbot-Raviv, and Dubowski (2017) measured total pesticide drift (both gaseous and particulate phase) following ground-based application in an apple orchard, using active sampling via polyurethane foam (PUF) plugs at various heights. Their results showed the importance of vertical profile measurements as both primary and secondary drift reached beyond trice canopy height (i.e., beyond 10 m for this orchard). Other recent studies (Grella, Gallart, Marucco, Balsari, & Gil, 2017; Torrent et al., 2017) examined the influence of drift reducing nozzles, sprayer settings and environmental variables on drift. One issue arising from both studies is that, in addition to nozzle type, tree shape (canopy dimensions) influences spray drift vertical profile at a height much beyond that of the crop/tree, and that one needs to perform measurements at different heights in order to estimate drift correctly.

The sampling methods used in the above studies are able to measure low concentrations but most of them require tedious lab preparation/analysis. Also, achieving high spatial coverage requires locating samplers at numerous sampling points. Besides these traditional off-line approaches, an increasing number of studies are considering the development of real-time techniques. For instance, (Gil, Llorens, Llop, Fàbregas, & Gallart, 2013; Moore et al., 2015) have demonstrated LIDAR (light detection and ranging) capabilities for measuring aerosol backscatter and extinction coefficients. Gil et al. (2013) compared the LIDAR performance to a deposition test using petri dishes. The LIDAR showed good correlation with the deposition collectors, but the results also revealed a possible influence of the droplet size on the measurement quality compared to the passive collectors. Recent studies using LIDAR for spray drift assessment have shown the potential of using such a system for high frequency measurements (Gregorio et al., 2014, 2016). These studies demonstrated the high correspondence of the LIDAR measurements to the passive collectors and showed that a significant portion of the drift occurs at up to at least twice the height of the canopy. However, despite its abilities, and convenient deployment, LIDAR has limited capabilities for identifying aerosol chemical composition.

An alternative technique is the open path Fourier transform infra-red (OP-FTIR) spectroscopy. OP-FTIR has been successfully applied for gas detection and identification in many fields of research (Hashmonay & Yost, 1999a; Hashmonay, Yost, Mamane, & Benayahu, 1999; Hashmonay & Yost, 1999b; Horrocks et al., 2001; La Spina et al., 2013; Todd et al., 2001). One of the most promising features of the technique is the measurement of fluxes and source localisation using tomography computation and mathematical inversions when the device is mounted on a positioner and several black bodies/retro-reflectors are incorporated in the experiment (Hashmonay et al., 1999; Hashmonay & Yost, 1999a; Todd et al., 2001). Few studies have investigated the potential of OP-FTIR for aerosol detection and they have mainly focused on measurements of water droplets in confined environments (Hashmonay & Yost, 1999b; Kira, Dubowski, & Linker, 2015; Kira, Linker, & Dubowski, 2016a; Wu, Chen, Chen, Yang, & Chang, 2007). Hashmonay & Yost (1999b) examined the OP-FTIR suitability to measure droplets. They measured micrometre-sized water droplets and were able to model their IR spectrum using inverse modelling based on Mie approximations and droplet size distribution. This finding is important because it demonstrates the OP-FTIR's potential to quantify aerosol concentrations without a-priori information of droplets size distribution. Kira et al. (2015) showed the feasibility of detecting spray drift from agricultural sprayers using passive OP-FTIR. Kira et al. (2016a) demonstrated the possibility of detecting and quantifying chemicals both in the gas phase and in the condense phase. Ethylene glycol was quantified simultaneously in both phases demonstrating a great potential for partition between the phases when measuring semi-volatile materials. The feasibility of detecting in real-time the spectral signature of organic compounds inside spray droplets during pesticide application