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Influence of spray characteristics on potential spray drift of field crop sprayers: A literature review

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ABSTRACT

Spray drift is a practical consequence of agricultural spraying operations. Because of the agronomical and environmental impacts of this phenomenon, drift has been widely studied and extensive information is available. Here we present a literature review on the relationships between global physical descriptors of agricultural sprays, air conditions and resulting drift, generally studied in wind tunnels. Basic physical factors are droplet size, droplet velocity, and the physicochemical characteristics of the sprayed product. When possible, data available in the literature are collated to draw trends. Contradictory information sometimes appears especially regarding droplet velocity and drift control. The main physical factors consist generally of medians such as Volume Median Diameter (VMD or Dv50) that do not always represent the heterogeneity of a spray and especially the spatial distribution of particle size and velocity. Technological parameters such as nozzle height, spray angle, travel speed are then related to initial physical factors and their contribution to driftability of sprays.

1. Introduction

Pesticides were extensively used in farmland after the discovery of DDT (Dichloro Diphenyl Trichloroethane) in 1939. About 3 billion kg of pesticides are applied each year with a purchase price of nearly 40 billion US $/year (Pimentel, 2005). Pesticides are used to increase both productivity and quality of cultivated crops. On the other hand, they can cause serious environmental and public health problems. Consequences of pesticide application may cause persistent problems in rural and urban areas due to the transport of polluting agents from the crop-growing areas to air, water and other natural resources, via different pathways (Gil and Sinfort, 2005). Spray drift may involve exposure of bystanders, residents, livestock, terrestrial and aquatic ecosystems to pesticides (Hilz and Vermeer, 2013).

Spray drift has always been one of the major concerns in the spray application industry. A common definition of spray drift is given through several organizations including the US Environmental Protection Agency (EPA), British Crop Protection Council (BCPC) and International Organization for Standardization (ISO). Spray drift can then be defined as the physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter from the target site to any non- or off-target site due to wind conditions (EPA, 2001; ISO 22856-1, 2008; BCPC, 1986). Spray drift may take several forms as droplet, dry particles or vapor. Particle drift increases when water and other pesticide carriers evaporate quickly from the droplet leaving tiny particles of concentrated pesticide. Vapour may arise directly from the spray or by evaporation of pesticide from sprayed surfaces (William and Smith, 2004). However many registered formulations are characterized by a low vapor pressure limiting the evaporation of active ingredients (Miller, 2003).

Spray drift is a complex phenomenon due to the combination effect of spraying equipment design, crop architecture, atmospheric conditions and the physicochemical properties of the spray mix. As such, the concomitant study of the influence of all parameters cited above appears unrealistic and literature mostly focuses on the influence of few parameters at a time. Main studies refer to (a) spray characteristics such as droplet size, spray shape and angle (Foqué et al., 2012), physicochemical properties of spray liquid (Butler Ellis and Tuck, 1999; Miller and Butler Ellis, 2000; Butler Ellis and Bradley, 2002; Herbst, 2003; Heinlein et al., 2007), (b) operating conditions : spray application technique (Van de Zande et al., 2003), boom height (De Jong et al., 2000; Baetens et al., 2009), operating

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pressure (Nuyttens et al., 2007b) and driving speed (Miller and Smith, 1997; Ghosh and Hunt, 1998; Womac et al., 2001) and (c) meteorological conditions (Threadgill and Smith, 1975; Miller, 1993; Miller et al., 2000; Gil and Sinfort, 2005).

Typical evaluation of spray drift is achieved through field tests with a complete sprayer (Ravier et al., 2005) whereas drift potential assessment generally requires a wind tunnel where generally only one nozzle is tested. Both methods are based on sampling process through a large variety of artificial collectors (Salyani, 2000; Salyani et al., 2006; Ferreira et al., 2010). Each method has its own advantages and disadvantages in terms of significance of drift data and repeatability due to atmospheric condition control (Hewitt and Wolf, 2004; Carlsen et al., 2006; Nuyttens, 2007; De Schampheleire et al., 2008; Donkersley and Nuyttens, 2011). Wind tunnel experiments provide an efficient method for supporting and complementing the data derived from field experiments. They allow the use of driftability indices, relative drift factors or drift potential factors to be developed for spray equipment (Walklate et al., 2000).

The objective of this paper is to draw a synthetical literature review on comprehensive works about spray drift to identify which physical factors were analyzed and when possible, compare the results. This paper focuses on experimental approaches developed in wind tunnels bringing some theoretical considerations, additionally. Modeling aspects are not covered in the scope of this paper.

A systemic representation of drift physical factors was adopted in this study as given in Fig. 1. In this figure three main systems are identified: (i) droplets, (ii) the spray pattern and (iii) external conditions. Drift potential can be attributed to a combination of these systems. It is obvious that the system “droplets” is a sub-system of the system “spray” but this representation was chosen to evidence that external conditions can interact both with individual droplets and their characteristics but also with the spray in its globality. The measurable characteristics of each system are indicated in boxes. This paper investigates how some measurable characteristics can be linked with spray drift as measured in a wind tunnel considering data present in the literature.

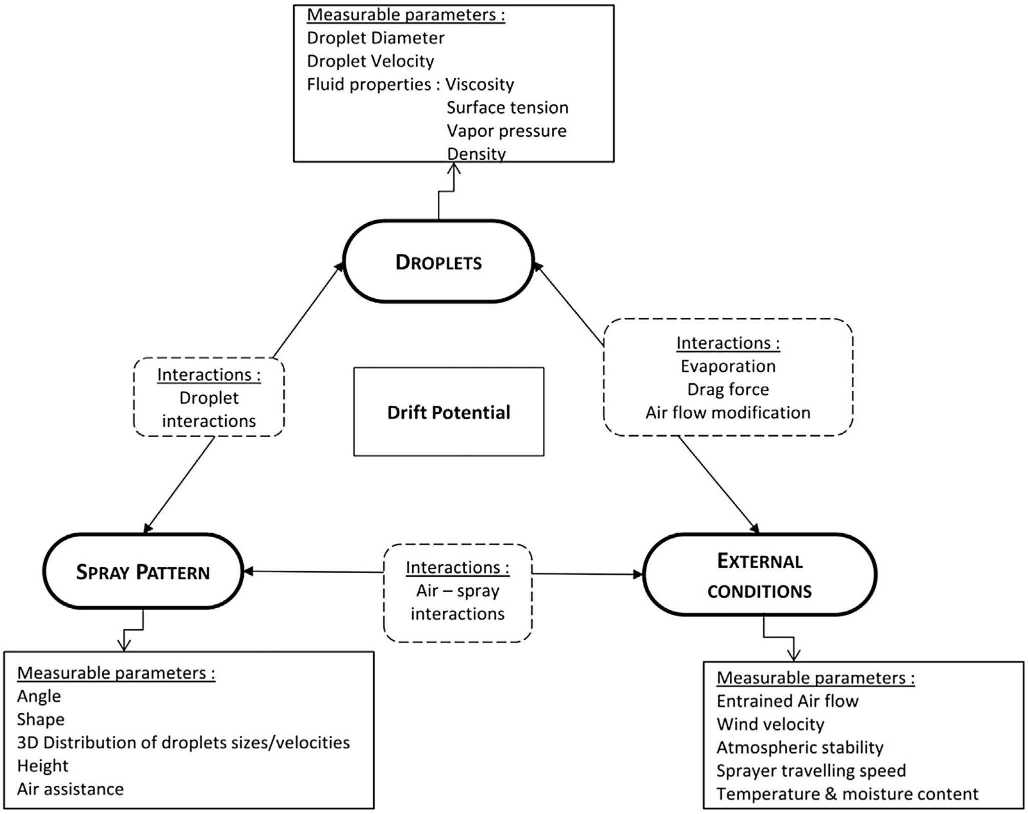

Fig. 1. Systemic representation of spray components contributing to drift potential. Interactions between components and components measurable parameters are indicated in dash and solid rectangles respectively.

2. Droplet characteristics

At the droplet level, drift corresponds to a modification of droplet trajectory induced by the drag force due to external air velocity. The expression of the drag force F_d is given by Eq. (1):

$$F_d = \frac{1}{2}\rho_a C_d A (V_d - V_a)^2 [\mathrm{N}] \tag{1}$$

where F_d is the drag force, C_d is the drag factor depending on the shape of the droplet (usually supposed spherical) and the Reynolds number, A is the frontal interaction area ($\pi D^2/4$) in m^2, V_a and V_d the velocities of air and droplet respectively, in m s^{-1} and ρ_a the air density in kg m^{-3}.

The drag force is then directly proportional to the square diameter and this factor is, by far, the most investigated parameter at the laboratory level. However, it also appears in this expression that the droplet relative velocity is an influential factor. In a first approach, one can consider that C_d is constant. The last influencing factor might then correspond to the density of the fluid.

Eq. (1) corresponds to a dynamic process: diameter (A) may change with evaporation, V_a is not constant (neither in time nor in