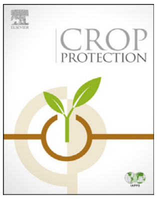
Crop Protection 89 (2016) 231–238

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro



Pressure, droplet size classification, and nozzle arrangement effects on coverage and droplet number density using air-inclusion dual fan nozzles for pesticide applications

J. Connor Ferguson [a, b, *], Andrew J. Hewitt [b], Chris C. O'Donnell [b]

[a] *School of Agricultural Sciences, Northwest Missouri State University, Maryville, MO, USA*
[b] *Centre for Pesticide Application and Safety, The University of Queensland, Gatton, Queensland, Australia*

A R T I C L E   I N F O

Article history:
Received 7 June 2016
Received in revised form
25 July 2016
Accepted 26 July 2016

Keywords:
Spray drift
Kromekote
Droplet deposition
Image J
Pesticide efficacy
Nozzle

A B S T R A C T

Spray applications are most effective when they cover the greatest per unit area, improving target pest control. In order to optimize spray applications, nozzle companies have developed new designs that seek to provide the greatest and most uniform coverage per target unit area. While dual fan nozzles have been examined against single fan nozzles in several studies, there has not been a comprehensive comparison of multiple nominal flow rate and multiple dual fan nozzle types. This study sought to examine pressure, droplet size classification, and nozzle arrangement effects on droplet number density on horizontal artificial collectors using a fixed application rate. The relationship between coverage and nozzle type was significant ($P < 0.001$) as was the relationship between coverage and pressure ($P < 0.001$). The 207 kPa pressure resulted in the highest coverage for every nozzle type except the alternating TADFs (ATADF)s. The GAT 11003 resulted in the highest coverage overall with 39.6% at the 207 kPa pressure, followed by the TADF 11005 and TADF 11003 at 38.6% and 38.3% coverage respectively. The effect of pressure was significant for the droplet number density ($P < 0.001$) as was the effect on droplet number density from nozzle type ($P < 0.001$). The 414 kPa pressure resulted in the highest droplet number density for all nozzle types except the AITTJ 11003 and the MDD 11004. The GAT 11003 and GAT 11004 produced the highest overall droplet number densities with 73.0 and 72.6 droplets cm^2 at the 414 kPa pressure. The GAT 11003 had the greatest droplet number density at every pressure. Nozzle arrangement has a significant effect on spray coverage with asymmetric dual fan nozzles, and it would be recommended to alternate these nozzles on a spray boom to increase coverage especially at higher application speeds. Results from this study show that an applicator can select a coarser droplet size classification without observable loss in coverage, while greatly reducing the drift potential of the application.

1. Introduction

A spray application is most effective when the optimal droplet size for the intended target is utilized. In order to deliver optimal sprays, nozzle companies have developed innovations that aim to provide the greatest coverage per unit area. One recent development is the use of an air-inclusion dual or twin fan design with forward- and rearward-facing orifices to deposit droplets prior to, and after the boom has passed over the target (Greenleaf, 2016; Hardi, 2011; Pentair, 2014; Teejet, 2011). These designs seek to increase the coverage on specific parts of the crop (e.g. wheat heads for protection against head scab) and to improve crop canopy penetration. Canopy penetration greatly influences pesticide efficacy, especially for invertebrate and fungal pest control. When sprays do not distribute evenly through canopies, their effectiveness greatly decreases (Uk and Courshee, 1982; Wolf et al., 2000), which can necessitate reapplication due to poor target pest control. Herbicide efficacy is strongly linked to the extent of crop canopy penetration (Knoche, 1994).

Pesticide spray drift is governed by the spray droplet size (Hewitt, 1997a), and previous research has shown that droplets below 150 μm often have the greatest drift potential (Byass and Lake, 1977; Grover et al., 1978). The US Environmental Protection Agency (EPA) definition of spray drift is “the physical movement of

---

[*] Corresponding author. Plant Protection Specialist, Northwest Missouri State University, Maryville, MO, USA.
E-mail address: cferguson@nwmissouri.edu (J.C. Ferguson).

http://dx.doi.org/10.1016/j.cropro.2016.07.032
0261-2194/

a pesticide through the air at the time of application or soon thereafter, to any site other than the one intended for application" (EPA, 1999). With increased pesticide spray drift as a concern, the market has shifted toward air-inclusion nozzles in order to produce larger droplets to reduce the application drift potential.

Air-inclusion nozzles work through the Venturi process whereby air is drawn into the nozzle which mixes in a chamber and interacts with the fluid, to produce air filled droplets (Dorr et al., 2013). Air-inclusion nozzles often also have a pre-orifice chamber aimed to increase the droplet size and act as a further drift reduction technology (DRT). In recent years, many nozzle manufacturers have developed new dual fan air-inclusion nozzles (Anonymous, 2016a, 2011a, 2011b, 2014).

Dual fan nozzles have been evaluated previously for coverage and efficacy comparisons against single fan nozzles. Studies which examined nozzle type effects for coverage and canopy penetration observed similar deposition amounts for both dual and single fan nozzle types (Derksen et al., 2008, 2014; Hanna et al., 2009; Ozkan et al., 2012). Research determining droplet size classification effects on post-emergence herbicide efficacy for winter grass control observed no differences in efficacy between an air-inclusion dual fan nozzle to single-fan nozzles, even single fan nozzles with a finer droplet size classification (Ferguson et al., unpublished). Other studies which examined only coverage observed similar or improved deposition with dual fan nozzles compared to single fan nozzles of a similar droplet size classification and nominal flow rate (Robinson et al., 2000; Turner and Matthews, 2001; Ozkan et al., 2006; Derksen et al., 2007; Wolf et al., 2009; Wolf and Daggupati, 2009; Guler et al., 2012). Another study which sought to compare the effects of coverage and canopy penetration over three application volume rates observed that an air-inclusion dual fan nozzle (TADF 11002) resulted in similar and sometimes improved coverage compared to other single fan nozzles with a similar droplet size classification (Ferguson et al., 2016a).

A design principle that benefits dual fan nozzles is the spray plume angle reduction from the nozzle to the plant, intended to increase spray deposition. It is well known that the spray deposition is maximized when the target is perpendicular to the droplet trajectory (Elliott and Mann, 1997; Richardson and Newton, 2000). Dual fan nozzles lessen the plume angle to the target which can improve droplet deposition on target surfaces (Gossen et al., 2008). When the rearward plume angle is increased, the drift potential from the application can increase, especially with a faster driving speed. Research has shown that droplet deposition and efficacy are improved on vertical leaf surfaces (e.g. grasses) when sprays are applied at a forward or rearward application angle to the target (Combellack and Richardson, 1985; Richardson, 1987; Dorr, 1990; Jensen, 2007, 2010; 2012; Jensen and Nielsen, 2008). The longer droplets are suspended in the air, the greater the spray drift potential (Maybank et al., 1978). However, a recent spray drift study, observed that a Coarse droplet size classification air-inclusion dual fan nozzle (TADF 11002) produced similar drift values to other Coarse droplet size single-fan nozzles (Ferguson et al., 2016b).

While dual fan nozzles have been compared to single fan nozzles in several spray coverage and efficacy studies (Derksen et al., 2008, 2014; Hanna et al., 2009; Ozkan et al., 2012; Ferguson et al., unpublished, 2016a; Wolf et al., 2009; Wolf and Daggupati, 2009; Guler et al., 2012), there has not been a comprehensive study examining multiple nominal flow rate and multiple dual fan nozzle types. This study sought to examine pressure, droplet size classification, and nozzle arrangement effects on droplet deposition on horizontal artificial collectors using a fixed application rate. There were three study objectives: 1. Understand spray pressure effects on coverage and droplet number density at a fixed application volume rate; 2. Measure the droplet size classification effects on coverage and droplet number density; 3. Examine the nozzle arrangement effects for asymmetric dual fan nozzles on coverage and droplet number density.

2. Materials and methods

2.1. Nozzles and application parameters

A study to examine the spray pressure, droplet size classification and nozzle arrangement effects on coverage and droplet number density at a constant application volume rate using dual fan nozzles was conducted at the University of Queensland, Gatton, Queensland, Australia. Four dual fan nozzle types including three symmetric dual fan nozzle types (Air Induction Turbo Twin Jet - AITTJ, Guardian Air Twin - GAT, and Mini Drift Duo - MDD) and one asymmetric dual fan nozzle type (Turbo Drop Asymmetrical Dual Fan - TADF) across three nozzle nominal flow rates (03,04, and 05) were selected to compare deposition on artificial collectors (Table 1). The GAT 11005 was not provided by its manufacturer for inclusion in this study. Treatments are listed in Table 1. The TADF nozzles were also arranged in a manner, where every second nozzle was rotated 180° to the previous nozzle, generating an "alternating" pattern. This pattern was designated ATADF. A standard 187 L ha^{-1} application volume rate was applied at three different application pressures (207, 310, and 414 kPa) which required multiple driving speeds. The speeds at each pressure for every nozzle type are listed in Table 2. Each combination of nozzle and pressure was classified according to droplet size using ANSI/ASABE S572.1 reference nozzles (ANSI/ASABE, 2009). Treatments were made using a 6 m trailed boom sprayer (UA300B/20S/6BX, Croplands Equipment Pty. Ltd., Adelaide, South Australia, Australia) pulled behind an all-terrain vehicle (Yamaha Grizzly 350, Yamaha Motor Pty. Ltd., Wetherill Park, New South Wales, Australia). Nozzle spacing was 50 cm and boom height was 50 cm above the collectors.

2.2. Collector description and placement

Collectors were made from Kromekote® paper, a specialty type of photo paper and each card measured 27.6 by 76.0 mm. Cards were sprayed with water and a 0.4 g L^{-1} addition of Brilliant Blue (Tintex Dyes, Kelvin Grove, Queensland, Australia) dye. The use of Kromekote® cards for deposition analysis has been described previously (Ferguson et al., 2016a; Johnstone, 1960; Higgins, 1967; Hewitt and Meganasa, 1993). Each card was positioned horizontally on a 50 by 80 mm flat metal plate in a 6.4 cm tall planting pot filled with vermiculite. Pots and cards were arranged in a 3 by 3 grid with a 50 cm spacing (Fig. 1). The study design was 14 nozzles by 3 pressures with 9 replicate collectors for each treatment. This gave a total of 378 cards used for each day of the study. The study was conducted on April 19th and then the entire study repeated on April 20th, 2016. This gave 756 cards that were sprayed and analyzed in total.

2.3. Card analysis

Each card was separately photographed on a light table using a 12.4 MP digital single-lens reflex (DSLR) camera (Pentax K-r, Ricoh Imaging, Tokyo, Japan) 10 cm above the cards. Sprayed cards were analyzed using Image J software (Rasband, 2008). Each image was cropped to remove the background area, converted into 8-bit grayscale format, and then transformed into binary black and white to be analyzed for droplet number density and percent coverage (Ferguson et al., 2016a). Coverage was determined as the percent cover on the card from the blue dye of deposited droplets (Fig. 2).