Assessment of pesticide application method efficiency by high-speed image analysis

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Abstract

This paper investigates if increased blackgrass weeding efficiency by reduced volume per hectare observed during 2010 Arvalis field trials may be related to increased pesticide application method efficiency. Retention on blackgrass leaves was assessed by an image analysis method. The setup consists of a high-speed camera shooting drop impact on horizontal leaf target. An herbicide (Archipel® [125 g/ha] + Actirob® [1 l/ha]) was sprayed at the usual volume of 150 l/ha and at a reduced volume of 65 l/ha. Adjuvants use (Epsotop® [1%] + Heliosol® [0.5%]) was also evaluated at 65 l/ha to highlight the effect of mixture surface tension modification. Drop properties before impact were extracted by image analysis and a phase diagram derived. Volumetric proportions of impact types are determined inside 11 energy classes to assess the effect of formulation and application method.

The volume median diameter (VMD) before impact was slightly decreased by the reduction to 65 l/ha because of nozzle and pressure changes and also by the use of the adjuvants leading to the reduction of surface tension. Without adjuvants the reduction to 65l/ha increased the proportion of adhesion while rebound remained unchanged and fragmentation decreased. With adjuvants, drop fragmentation occurs for a lower energy class but the proportion of fragmentation also decreases with because of reduced VMD. A slight effect on the transitions between impact classes was observed because of formulation concentration change at reduced volume/hectare. A major effect of adjuvants on retention was highlighted as bouncing disappeared.

Key words: Spray retention, Field trials, Blackgrass, High-speed imaging, Reduced volume applied.

1. Introduction

For environmental and economic issues, the global trend is to reduce the dose of pesticides applied and the volume per hectare applied. Under these constraints, the challenge is to ensure an equally effective treatment. Extension services perform field trials in order to guide farmers toward application efficacy improvements. Weed control trials at early stage during 2010 (Perriot et al., 2011) in wheat resulted in an increased efficiency on blackgrass at half pesticide dose when spraying at 65 l/ha comparatively to 150 l/ha volume. At 65 l/ha, ryegrass control was also improved by adjuvant use but only a faint effect was observed because of too high control efficiency at 65l/ha. An explanation may lie in the theories of drop impacts on difficult-to-wet targets.

Spray retention on leaves is defined as the quantity of mixture effectively retained on the leaf surface per unit area. Retention is controlled by drop size and velocity, formulation physicochemical properties as well as surface properties (Taylor, 2011). Superhydrophobicity appears on hydrophobic materials when the small scale roughness is increased. As a consequence, the water static contact angle may exceed 160° on these surfaces. Two models that describe the wetting of superhydrophobic surfaces are often used to explain the different drop behaviors during impact, the Wenzel non-composite regime and the Cassie-Baxter composite regime (Zu et al., 2010). The Wenzel non-composite regime, often referred as pinning, is characterized by the sticking of the liquid which is anchored in the surface cavities. In the Cassie-Baxter composite regime, the liquid stands on the pillars of the surface and some air is trapped beneath the drop in the valleys of the structure. The liquid can be easily removed from the surface. The height and distance between the pillars is a critical parameter to keep the drop in a Cassie-Baxter regime. Moreover, the energy of drop during impact is also an important parameter. The outcome of a low kinetic energy drop will be different from that of a high kinetic energy drop. Therefore different outcomes during drop impact can be identified on these surfaces depending on drop kinetic energy and the liquid surface tension (Fig. 1).

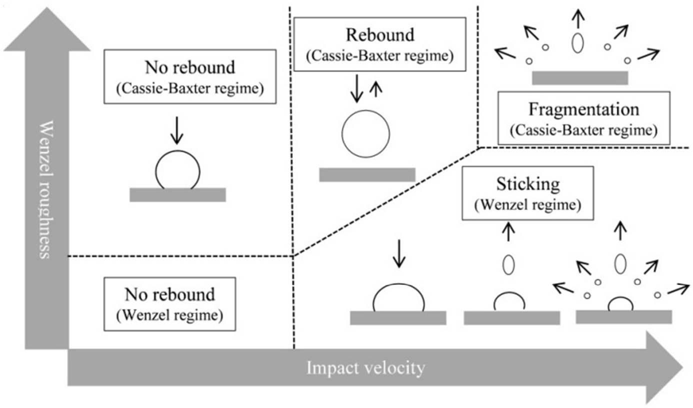

FIGURE 1: Drop impact phase diagram on horizontal superhydrophobic surface for a water drop (from Rioboo et al., 2008), depending on drop velocity and wetting regimes.

It was assumed that retention efficiency was modified by the application method. The main objective of the paper is to test the effect of spray application technique on blackgrass weeding. To support this objective, the retention is studied by high-speed imaging at the drop scale level. This method was previously devised and the link between impact outcomes and wetting regimes has been discussed (Massinon and Lebeau 2012a). The method was validated by comparing retention on outdoor-grown wheat and on a synthetic superhydrophobic surface (Massinon and Lebeau, 2012b).

2. Materials and Methods

2.1. Laboratory trial methodology

The assessment of spray retention was realized by the method previously described by Massinon & Lebeau (2012a). The dynamic bench was composed of a single nozzle mounted on a linear stage 50 cm above the target. Forward speed of the nozzle was adjusted to reach the required spray application volume. Spray products were agitated and pressurized in a stainless steel tank. Drop impacts on the target were recorded immediately before impact at high magnification with a high-speed camera (20,000 frames per second) coupled to a backlight LED lighting. Impact outcomes are identified by an operator. Size and velocity of sharp drops were determined by image analysis.

2.2. Experimental conditions

An herbicide (Archipel® [125 g/ha] + Actirob® [1 l/ha]) has been applied at two volumes per hectare in laboratory to compare the results obtained with those in fields trials. Firstly, an usual volume of 150 l/ha was applied with a XR11002 nozzle (Teejet®) at 0.2 MPa pressure. Nozzle forward speed was set to 5.2 km/h. Secondly, a reduced volume of 65 l/ha was applied with a XR110015 nozzle (Teejet®) at 0.15 MPa. Nozzle forward speed was set to 7.7 km/h. In addition, the effects of adjuvants (Epsotop® [1%] + Heliosol® [0.5%]) have been studied at a reduced volume of 65 l/ha.

Target surfaces were excised leaves excised from indoor-grown blackgrass and fixed on a U-shaped bracket. Spraying was performed on the adaxial face. Leaves were handled taking care not to alter their surface. Ten spraying were performed with a new leaf for each trial. A total of thirty sprayings were carried out.

3. Results

The impact outcomes observed on blackgrass leaf for both spray volumes as a function of drop diameter and velocity are presented in Fig. 2 – 4A where each point represents a drop impact. The impact phase diagram is discretized into 11 energy classes. The class boundaries correspond to a constant dimensionless Weber number of the drop before impact. The first limit was set to a 0.02 Weber number and higher limits follow a times 3 progression for a constant spacing in log/log scale. The Weber number ($We = \frac{\rho V^2 D}{\sigma}$) which represents the ratio between the drop kinetic energy and the drop surface energy (where ρ is liquid density, V is the velocity, D is the drop diameter and σ is the liquid static surface tension) was computed with the water surface tension value 72.2 mN/m. This way, we create an energy scale that depends only on the physical parameters of the drops. 11 was the higher impact energy class observed. For each energy class, the volume of drops for each impact outcome is computed and normalized regarding to the total volume in this energy class. These proportions are finally presented in stacked histograms (Fig. 2 – 4B).

Volumetric percentage in each impact class is computed on the basis of observed droplet diameters before impact. This method that allows a quantification of the proportion of the different outcomes during impact must be interpreted only as indicative because the number of drops used to compute them is quite low. However, an increase of the adhesion proportion was observed at a reduced volume of 65 l/ha (Table 1), which is corroborated by comparing Fig. 2 and 3 A. The rebound proportion remained almost unchanged at respectively 6 and 7% but the fragmentation decreased in return. This resulted mainly from the volume median diameter (VMD) that was slightly decreased by the reduction to 65 l/ha because of nozzle and pressure changes. The use of the adjuvants resulted in a complete disappearance of the rebound and Cassie-Baxter regime from trials (Fig. 4). With adjuvants, the splashing occurred for a lower energy class but the proportion of fragmentation decrease because of reduced VMD caused by dynamic surface tension.

Considering only the proportion of adhesion, the relative increase between 150 and 65 l/ha was about 18% in laboratory tests, which consistent with the efficacy increase highlighted with 2010 field trials. The proportion of drops undergoing a fragmentation in the Wenzel regime during impact (x) was reduced at 65l/ha. As part of the drop then sticks on the surface and increases, this class may also affect retention but the proportion remaining on the leaf is still to be investigated.

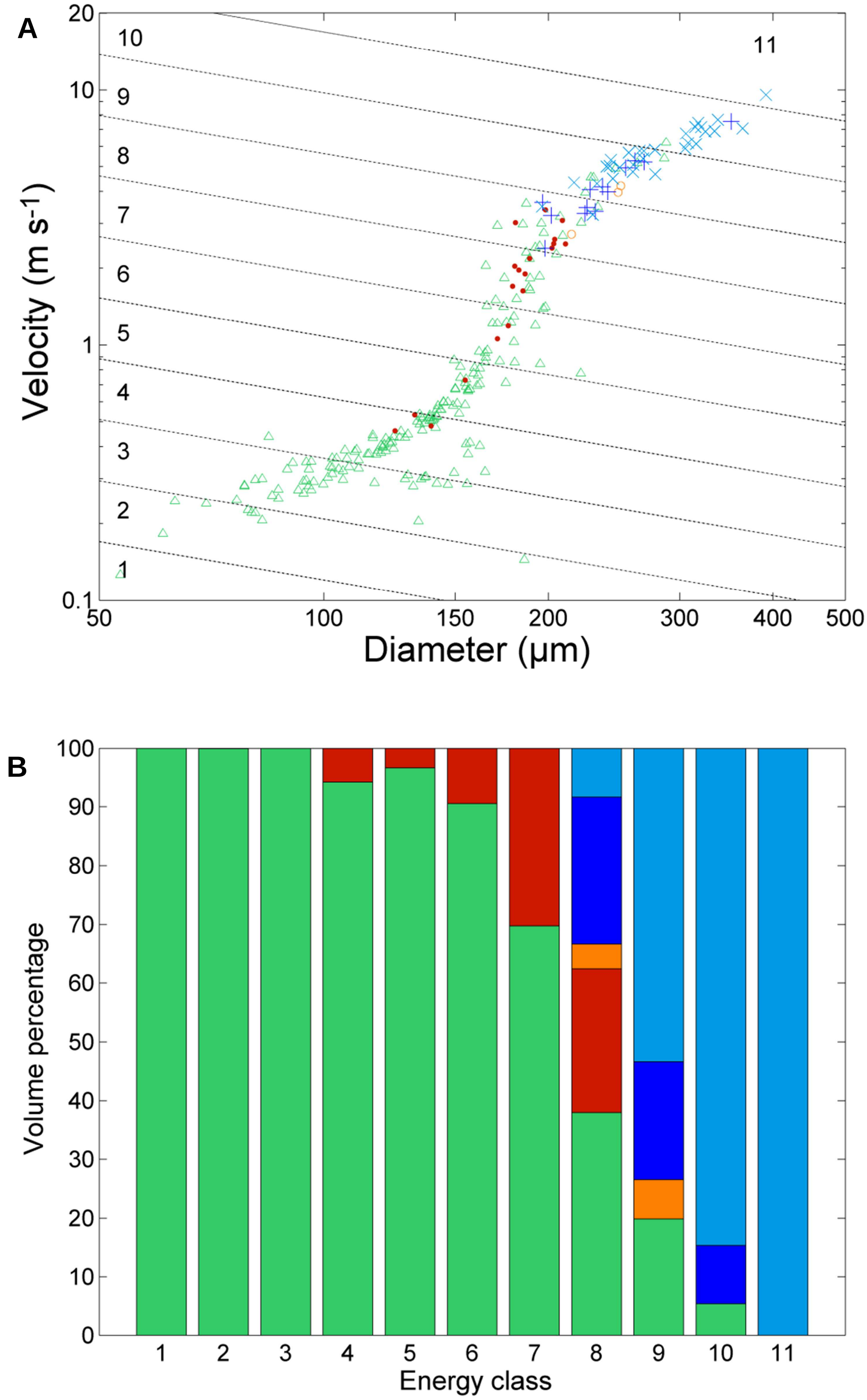

FIGURE 2: Laboratory spray results for 150 l/ha volume. (A) Drop impact phase diagram: Δ adhesion, ● rebound (Cassie-Baxter), ○ pinning rebound (Wenzel), × pinning splashing (Wenzel) and + complete splashing (Cassie-Baxter). Straight lines represent the boundaries between the 11 energy classes defined. (B) Normalized volume in each energy class for each impact outcome.

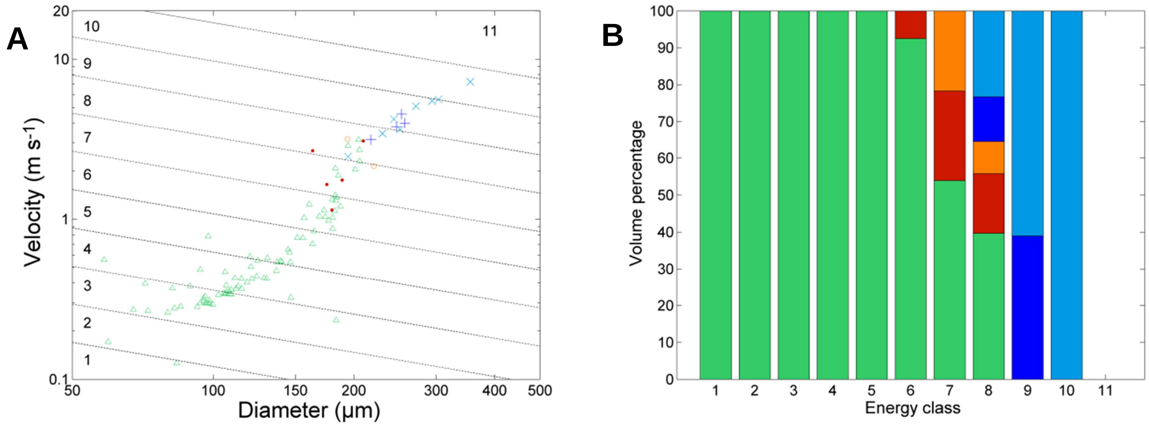

FIGURE 3: Laboratory spray results for 65 l/ha volume. (A) Drop impact phase diagram: Δ adhesion, ● rebound (Cassie-Baxter), ○ pinning rebound (Wenzel), × pinning splashing (Wenzel) and + complete splashing (Cassie-Baxter). Straight lines represent the boundaries between the 11 energy classes defined. (B) Normalized volume in each energy class for each impact outcome.

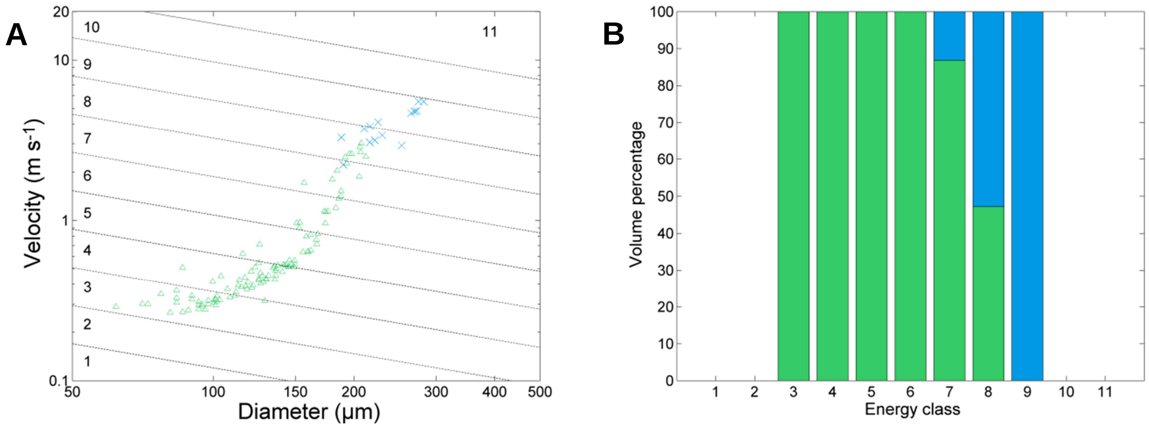

FIGURE 4: Laboratory spray results for 65 l/ha volume with adjuvants. (A) Drop impact phase diagram: Δ adhesion and × pinning splashing (Wenzel). Straight lines represent the boundaries between the 11 energy classes defined. (B) Normalized volume in each energy class for each impact outcome.

TABLE 1: Summary of data extracted from the imaging process averaged on ten replicates of spraying.

Formulation	without adjuvants		with adjuvants
Applied dose	150 l/ha	65 l/ha	65 l/ha
Adhesion, % volume	38	45	61
Rebound (Cassie-Baxter), % volume	7	6	0
Rebound (Wenzel), % volume	2	3	0
Fragmentation (Cassie-Baxter), % volume	12	12	0
Fragmentation (Wenzel), % volume	41	34	39
Number of drops	248	100	122
VMD (µm)	240	206	192
Volume observed (µl)	0.893	0.259	0.265

4. Discussion

On one hand, the increased efficiency observed in the Arvalis 2010 field trials at 65 l/ha is consistent with the small VMD change resulting from smaller nozzle caliber that allows 18% more volume of small drops to adhere at primary impact on the difficult-to-wet blackgrass leaf. However, the effect is quite faint. The efficiency improvement at reduced volume was not observed anymore in 2011 field trials, as both volumes showed bad efficiencies. On the other hand, the adjuvant interest was emphasized in the laboratory as the results clearly highlighted that the effect of the adjuvant use on retention is far higher that the effect of volume per hectare reduction but field trials where too efficient to mark any significant difference. It is clear that the response to the volume depends on numerous parameters such as the plant sensibility to sulfonylureas. As spray application efficiency in the fields rely on multiple, often non-linear factors, it remains difficult to explain field observations on the basis of a single variable as spray retention. However, the developed method increases the understanding of the interaction between physicochemical properties, drop and target characteristics. It can be used to guide future field trial setup.
Effect of spray angle, relation between impact and retention for the different impact outcomes are subject of further research to improve the understanding of parameters that may affect the efficiency at the field level.

5. Acknowledgements

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