Spray retention assessment combining high-speed shadow imagery and fluorescence techniques

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Spray retention

• Retention is mainly associated with droplet primary adhesion, while bouncing and splashing are seen as detrimental.

• Impact outcomes depend on leaf surface and spray mixture properties.
Leaf surface

• A **difficult-to-wet** leaf is simultaneously characterised by:
  
  – its **hydrophobic surface**: waxes render the surface hydrophobic
  – its **micro-topography** reducing the contact area available for droplets: veininess, hairiness: enhance the water repellency of the hydrophobic leaf surface

• Lotus effect: the water droplet static **contact angle** can exceed 150° = **superhydrophobicity**
Spray mixture

- On superhydrophobic species, **surfactants** are often used to enhance spray formulation performances by affecting the physicochemical properties of droplets, i.e. surface tension.

- Surfactants are known to modify the **wetting behaviour** of the droplets on the leaf surface by increasing the spreading.

- Dynamic surface tension = variation over time of liquid surface tension.
Wetting models

The **Cassie-Baxter** regime (non-homogeneous wetting)

Extreme water repellency

The **Wenzel** regime (homogeneous wetting) = pinning
Possible impact outcomes

Transition from Cassie-Baxter to Wenzel wetting regime is possible because of high impact pressure and low DST
Objectives

• The aims of the study are dual

  – Propose a **methodology** for characterising spray impact on leaves relying on the simultaneous observation of droplet impacts by high speed imaging and fluorescent tracer analysis of deposits

  – **Quantify** the amount remaining on a leaf after primary impact of droplets in Wenzel’s wetting regime on horizontal barley leaves
Dynamic test bench

- 50 cm nozzle height

CMOS 20000 fps
Lens
Target surface

LED lighting

2 m/s
High speed imaging
image processing

1) Digital image: ROI above the leaf
2) Background subtraction
3) Image binarisation
4) Droplet detection and identification
5) Droplet size
6) Droplet coordinates on 2 frames
7) Droplet velocity

8) Dimensionless Weber number $We = \frac{\rho V^2 d}{\sigma}$

9) Impact outcome identification according to the physical classification
Barley leaves

- Indoor grown
- Excised leaves: 10mm x 3mm
High speed imaging

data analysis: energy classes

- Tap water + 0.2g/L fluorescein on barley leaf
- XR11003VK @2bars 160 L/ha, 10 sprayings
High speed imaging

data analysis: energy classes

- Tap water + 0.1%v/v Break-Thru S240 + 0.2g/L fluorescein on barley leaf
- XR11003VK @2bars 160 L/ha, 10 sprayings
High speed imaging data analysis: energy classes

- Tap water + 0.25%v/v Li-700 + 0.2g/L fluorescein on barley leaf
- XR11003VK @2bars 160 L/ha, 10 sprayings

Retention: tap water < Li-700 < Break-Thru S240
DST: tap water > Li-700 > Break-Thru S240
High speed imaging
data processing: evaporation

• Because of evaporation, fluorescein concentrations in droplets increase

• Correction of the measured volume is required for making correlation between the two techniques

• This was achieved by resolving equations for the droplet transport, heat and mass transfer (according to Guella 2008, International Journal of Thermal Sciences 47 886–898)
## Spray retention

comparison between techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Volume (µl/0.3 cm²)</th>
<th>Tap water</th>
<th>Break Thru S240</th>
<th>Li700</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Av.</td>
<td>StD</td>
<td>Av.</td>
<td>StD</td>
</tr>
<tr>
<td>Observed volume¹</td>
<td>0.34</td>
<td>0.11</td>
<td>0.34</td>
<td>0.08</td>
</tr>
<tr>
<td>Adhesion</td>
<td>0.14</td>
<td>0.08</td>
<td>0.19</td>
<td>0.05</td>
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<tr>
<td>High speed imaging</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Rebound C-B</td>
<td>0.05</td>
<td>0.04</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Splashing C-B</td>
<td>0.00</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Splashing W</td>
<td>0.15</td>
<td>0.09</td>
<td>0.13</td>
<td>0.06</td>
</tr>
<tr>
<td>Spectrophotometry Retention</td>
<td></td>
<td></td>
<td>0.22</td>
<td>0.12</td>
</tr>
</tbody>
</table>

¹ Total volume of droplets landing on the leaf increased to account for evaporation.

**Retention = Adhesion + K * Splashing Wenzel**

K = % of droplet volume splashing in Wenzel regime that remains on the leaf due to pinning
# Spray retention

## pinning percentage

| Spraying | Tap water | | Break Thru S240 | | Li700 |
|----------|-----------| | | | |
| | | K | | K | | K | |
| 1 | 44,40 | 1,03 | 66,80 | 1,12 | 56,40 | 1,04 |
| 2 | 71,90 | 0,91 | 42,00 | 0,96 | 39,00 | 0,87 |
| 3 | 14,40 | 1,07 | 67,30 | 1,01 | 68,10 | 1,05 |
| 4 | 38,00 | 1,18 | 70,50 | 1,13 | 32,70 | 1,15 |
| 5 | 48,20 | 1,17 | 63,70 | 1,04 | 50,80 | 1,07 |
| 6 | 29,80 | 0,67 | 36,50 | 0,92 | 74,30 | 0,83 |
| 7 | 5,00 | 1,13 | 30,00 | 1,10 | 45,30 | 1,52 |
| 8 | 83,90 | 1,00 | 46,60 | 1,08 | 43,40 | 0,62 |
| 9 | 57,00 | 0,75 | 91,40 | 0,70 | 36,20 | 1,10 |
| 10 | 62,40 | 0,99 | 70,20 | 0,96 | 37,00 | 0,90 |
| Average | 45,50 | 0,99 | 58,50 | 1,00 | 48,32 | 1,02 |
| StD | 24,74 | 0,17 | 18,99 | 0,13 | 14,05 | 0,24 |
Conclusions

• Depending on the spray mixture, droplets fragmented in Wenzel regime accounted for 28-46% of retention at first impact, with a clear ranking as a function of DST.

• This contribution is not negligible and should be considered when modelling spray retention processes, especially on early growth stages and when using low-drift nozzles with surfactants (larger droplets more likely to splash).

• The coexistence of impact outcomes for the same impact energy is also important to be considered in retention models.
High speed imaging
results: volume percentages

• Ten trials

<table>
<thead>
<tr>
<th>Mixture</th>
<th>$V_{\text{tot}}$ (µl)</th>
<th>% Ad</th>
<th>% R CB</th>
<th>% Sp CB</th>
<th>% Sp W</th>
<th>VMD</th>
<th>Drops number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>3.44</td>
<td>41.6</td>
<td>14.2</td>
<td>1.1</td>
<td>43.0</td>
<td>317</td>
<td>627</td>
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<tr>
<td>Water + Break Thru S240</td>
<td>3.35</td>
<td>58.0</td>
<td>2.4</td>
<td>0.3</td>
<td>39.4</td>
<td>272</td>
<td>736</td>
</tr>
<tr>
<td>Water + Li 700</td>
<td>3.31</td>
<td>35.6</td>
<td>4.3</td>
<td>0</td>
<td>60.1</td>
<td>328</td>
<td>448</td>
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