Computer simulations of spray retention by a 3D barley plant: effect of formulation surface tension

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### Transport/drift
- Marchant (1977): droplet trajectories in a moving airstream
- Walklate (1987): random walk model (lagrangian) with turbulence statistics
- Reichard et al. (1992): CFD
- ...  
  - Cox et al. (2008): random walk, evaporation, plant architecture, velocity threshold

### Retention/droplet impact
- Brunskill (1956) and Furmidge (1962): involved parameters, droplet rebound
- Wirth et al. (1991): mechanisms, high speed imaging techniques, DST
- Forster et al. (2005): ‘universal’ model, droplet generator, velocities 1 to 3.5m/s, leaf orientation
  - Taylor (2011): review on wetting of leaf surface
  - Nairn (2013): ‘universal’ model for hairy leaves
- Dorr et al. (2014): droplet adhesion, rebound and splashing on single 3D leaf
• Thanks to the recent development of:
  • high-speed imaging: droplet impaction
  • low cost and accurate 3D scanners: plant phenotyping

• The objective:
  • develop a simulation tool enabling an independent investigation of the various parameters on spray retention
  • Including the possible impact outcomes on the actual plant surface and architecture

• Such a tool is helpful for:
  • targeting formulation properties in relation with the plant and the application technique
  • guiding the design of field trials
Model overview

- Nozzle settings
  - Mixture properties
  - L/ha

- Plant architecture

- Droplet impact behavior
  - \( f(\sigma, \rho, \theta, d, v) \)

- Virtual nozzle
  - D, V, directions immediately before impact

- Interception algorithm
  - Interception?
    - no: loss
    - yes

- Retention model
  - retention \( \mu l/cm^2 \)
Model overview

Nozzle settings
Mixture properties
L/ha

Plant architecture

Droplet impact behavior
$f(\sigma, \rho, \theta, d, v)$

Virtual nozzle

Interception algorithm

Interception?

Retention model

Retained

$\text{retention } \mu l/cm^2$

D, V, directions
immediately before impact

loss

no
1. Virtual nozzle – Draw of droplet diameters

Nozzle kind and size
Spraying pressure
Liquid properties
Nozzle height

Experimental droplet size distribution (imaging)

Adjustment by the method of moments (Pearson system)
\[ \mu, \sigma, \beta, \gamma \]

Model input

Draw until a nominal volume is reached
Droplet velocities are randomly drawn from normally distributed pseudorandom numbers $N(\mu, \sigma)$

- $\mu$ : computed from droplet transport and evaporation equations (still air assumption)*
- $\sigma$ : 0.1 m.s$^{-1}$

- Droplet trajectories are assimilated as straight lines with random directions on a very short distance above the plant (from experimental impact angle distributions)

- Example of volume repartition on 1 square metre of soil at a nominal sprayed volume of 100 L.ha$^{-1}$
Model overview

Nozzle settings
Mixture properties
L/ha

Virtual nozzle

D, V, directions immediately before impact

Interception algorithm

Interception?
no
loss
yes

Retention model

Droplet impact behavior
\( f(\sigma, \rho, \theta, d, v) \)

Retention
\( \mu l/cm^2 \)
2. Interception algorithm - Plant architecture

- Structured Light Scanner

- Combined views at 360° for 3D reconstruction of the plant
- Scanning time about 10 min

Barley at early grow stage = difficult-to-treat target: small, stiff and superhydrophobic leaves
Ray/triangle intersection algorithm

Model overview

Nozzle settings
Mixture properties
L/ha

Virtual nozzle

D, V, directions

Interception algorithm

Interception?

loss

yes

Retention model

Droplet impact behavior probabilities
$f(\sigma, \rho, \vartheta, d, v)$

retention
$\mu l/cm^2$

Mixture properties
L/ha
3. Retention model - Spray application bench

Pulsed LED lighting
Excised leaf

CMOS 20000 fps
10 µs exposure time

FOV: 10mm x 2 mm
Water droplet on superhydrophobic leaf surfaces:

\[ We = \frac{\rho \, v^2 \, d}{\sigma} \]
3. Retention model - Droplet impact behaviors on SH surfaces

From image analysis:

\[ We = \frac{\rho v^2 d}{\sigma} \]

Energy class 1: \( We < 0.02 \)

Energy class 2: \( 0.02 < We < 0.06 \)

... Energy class 11: \( We > 394 \)
3. Retention model - Spray impact behaviors on barley leaf

Tap water

Tap water + 0,1% v/V nonionic trisiloxane surfactant

Horizontal leaves

+ : relative volume of this energy class
Logistic regression: core of the retention model

\[ y = \frac{A}{1 + \exp\left(\frac{a - x}{b}\right)} \]
4. Simulations: effect of adhesion proportion

- 100 different droplet size distributions from 6 flat-fan nozzles
- 7 impact histograms: gradual increase of adhesion proportion
- No liquid remaining on the surface after a splashing (no pinning)

Retention ↑ with ↑ adhesion proportion

Coarser nozzles less influenced by adhesion proportion
4. Simulations: effect of pinning proportion

Retention = adhesion + $K \times$ splashing

$K \in [0, 1]$

- Finer sprays are not influenced by the pinning proportion because they contain no splashing droplets.
- The increase of retention thanks to increasing adhesion is reduced while increasing spray coarseness.
4. Simulations: effect of plant size

11003 flat fan nozzle: F/M, VMD=239µm
100L/ha

Retention ↑ with ↑ adhesion proportion
CV ↑ with ↓ plant size
CV ↑ with ↓ adhesion proportion
5. Conclusions and perspectives

- The presented modeling approach at the droplet scale provided a suited tool for sensitivity analysis:

  nozzle kind and size, pressure, volume per hectare, spray mixture physicochemical properties, plant species and growth stage

  could be screened to determine the best spray application and formulation technologies maximizing the retention on a given target

- Include air movements by means of a random walk model
- Extend the model to secondary impacts
6. References


