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# Spraying quality assessment of a mist blower used on banana crops.

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## Abstract

This paper introduces spraying quality assessment of a mist blower as a potential option to replace aerial spraying on banana crops. Depending on the crop protection formulation either water or mineral oil are planned to be used as spraying fluids. Spraying quality was first evaluated through droplet size distribution for different flow rates measured in front of the centre axle of the mist blower and at +/- 2 cm height from the centre axle. Results show significant differences between fluids and measurement parameters (flow rate and position). As a second step, ground distribution after dynamic spraying with was measured with Petri dishes testing bench for different flow rates of water and mineral oil. As a result, ground distribution showed a high dependence to the nature of fluids as well as flow rates values. Finally ground deposits were estimated for either water or oil applications by using an advection-diffusion model for different flow rates. Results indicate that model settings involve satisfying prediction for water but not for oil. In this last case, authors suggest several assumptions in terms of experimental settings adjustments and peculiar behaviour of oil droplets.

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## 1. Introduction.

Until nowadays, crop preservation against *Mycosphaerella musicola* (Yellow Sigatoga) in French Caribbean banana crops are mainly achieved by using airborne spraying. Mineral oil (such as Banole™) is commonly used against Sigatoga, with or without chemicals. Meanwhile water can also be used as crop protection spraying fluid on banana trees.

The European Directive 2009/128/CE (Anonymous, 2009) on sustainable use of pesticides strongly recommends the abortion of aerial spraying of pesticides unless no other valuable solution exists. In this context Cemagref was named by French Ministry of Agriculture to study any terrestrial alternative to aerial spraying upon banana crops.

Previous studies on spraying characterisation (Salyani and Fox, 1999; Hanks, 1995; McWhorter et al., 1988) showed significant discrepancy in terms of spraying quality between pure water and mineral oil for different kind of spraying technical settings suggesting a strong effect of the fluid nature on particle sizes distribution for analogous experimental conditions. Spraying quality from airborne spraying was also investigated (type of nozzle, size of the airborne boom, etc.) (Salyani and Cromwell, 1992).

This study issue is to evaluate the spraying quality of terrestrial solutions such as mist blowers, (pneumatic cannon sprayer) as a potential option to replace airborne treatments.

## 2. Materials and experimental setup.

### 2.1. Mist blower

The tested sprayer was a Martignani™ B 748 Mist blower (pneumatic canon sprayer) fitted with 4 peripheral diffusers for standard flow rates ( $1.3$  to  $9 \text{ L}\cdot\text{min}^{-1}$ ) and a central diffuser used for ultra low volume ( $0.6 \text{ l}\cdot\text{min}^{-1}$ ) (Fig. 1). Working pressure was  $1.5 \text{ bar}$ .



Figure1 : Peripheral and central diffusers.

The engine speed was set up to produce a wind speed of  $50 \text{ m}\cdot\text{s}^{-1}$ . Flow rates were measured by using blower electromagnetic flow-meter ( $5 \text{ Hz}$ ) and compared with volumetric flow-meter Aquadis™ with  $0.1 \text{ L}$  accuracy.

### 2.2. Light scattering particle sizer.

A Malvern Spraytec™ device was placed at  $30 \text{ cm}$  from the blower outlet with measurements at  $0$  and  $\pm 2 \text{ cm}$  compared to the canon axle (Fig. 2)



Figure 2 : Droplet size measurements

Each measurement was repeated at least 3 times in the same conditions (fluid, flow-rate, position). Results were expressed in terms of droplet size distribution with all necessary distribution characterization ( $D_{v10}$ ,  $D_{v50}$ ,  $D_{v90}$ , Span, etc).

Literature on such an experimental particle seizer indicates easy setting up as well as reliable reproducibility of results (Dayal et al., 2004; Triballier et al., 2003).

### **Calibration**

As particle size is largely greater than the wavelength of the laser beam, diffraction is observed accordingly to the Fraunhofer theory. In this case, it is no need to consider the refraction index of the fluid (1.33 for water and 1.5 for oil).

Capacities in Droplet size scale are from 0.1 to 1000  $\mu\text{m}$ .

### **Calculated Parameters**

$D_{v10}$  : Droplet size for which 10% of the total volume is obtained

$D_{v50}$  : Droplet size for which 50% of the total volume is obtained

$D_{v90}$  : Droplet size for which 90% of the total volume is obtained

Sauter Mean Diameter :  $D^3/D^2$

Span : distribution span  $(D_{v90}-D_{v10})/D_{v50}$

### **2.3. Experimental setup for ground deposits evaluation.**

Tree lines of Petri dishes supports were placed every 50 cm up to 20 m (Fig. 3) in accordance with ISO/CD 24253-1 (Anonymous, 2009). Wind speed and direction were recorded with a 10 Hz Almemo™ data logger ; means were respectively 0.5  $\text{m.s}^{-1}$  and 85 °.



| Flow rate<br>( $\text{L.min}^{-1}$ ) | Field dose<br>Water ( $\text{L.ha}^{-1}$ ) | Field dose<br>Oil ( $\text{L.ha}^{-1}$ ) |
|--------------------------------------|--|--|
| 1.3                                  | 16   | 18                                       |
| 4.5                                  | 90   | 89                                       |
| 7.5                                  | 100  | 118                                      |
| 9                                    | 165  | 133                                      |

Table 1 : Estimated field dose depending on flow rates @ forward speed of 5  $\text{km.h}^{-1}$

Figure 3: Sampling setup for ground deposits.

Flow rates were measured for 5 different settings (from 16 to 145  $\text{L.ha}^{-1}$ ) for oil and water. Ultra Low Volume configuration (central diffuser) was 20  $\text{L.ha}^{-1}$ .

Pure Water was completed with 125  $\mu\text{g.L}^{-1}$  Brilliant Sulfoflavine (BSF) dye and Mineral Oil was added with CF006 dye. After spraying phase, Petri dishes were individually collected. Dye contains were measured through spectrometry (Perkin Elmer) by using a sampling-solution. Results are directly expressed in terms of field dose at the different sampling positions.

Collected fraction (%) is calculated in each case by integration of the collected volume along the collect lines. Each collector is supposed to represent an area of  $\frac{1}{2}$  m<sup>2</sup> between 0 and 10 m distance from the outlet and 1m<sup>2</sup> from 10 to 20 m.

## 2.4. Advection-diffusion model

For this study, a model based on an advection-diffusion approach was developed and applied to the droplet population. Starting from distributions percentiles (Dv10, Dv50 and Dv90), a range of diameter was reconstructed and led to a sum of gaussian functions where a single function was defined for a given class of diameter. The interest of such development was underlined by Baetens et al. (2009). Satisfying results were already obtained for flat fan nozzles distributions within a wind tunnel. The droplet population was described with 100 diameter classes of equal diameter size. For the advection part, the trajectory of a droplet from a given class diameter droplet is computed from the first Newton law, taking into account the following representation of air flow velocity :

$$\frac{V_0}{V(x)} = \frac{1}{k} \left( \frac{x}{D_{jet}} - XD \right)$$

where  $V_0$  stands for the initial velocity of the air jet (50 m/s),  $k$  is a setting parameter,  $V(x)$  is the air velocity at a distance  $x$  from the output,  $D_{jet}$  is the diameter of the output and  $XD$  is the ratio  $x_0/D$ ,  $x_0$  being the distance between the output and the fictive origin of the jet. This expression represents the mean centerline velocity decay for fully developed axisymmetric turbulent jets (Rajaratnam, 1976).

The diffusion part describes the distribution around the impact point of the droplet with gaussian laws which standard deviation is given by :

$$\sigma_d^2 = D \times t_d$$

where  $t_d$  is the elapsed time from the ejection of the droplet and  $D$  a coefficient representing diffusion conditions.

The two factors,  $k$  and  $D$ , were computed to fit experimental data using root mean square minimisation.

## 3. Results

### 3.1. Droplet size measurements.

#### *Effect of the fluid nature.*

Considering all experimental data, Figure 4 shows the results for pure water and mineral oil in terms of  $D_{v10}$ ,  $D_{v50}$  and  $D_{v90}$ . In general, the ratio between  $D_{vOil}/D_{vWater}$  appeared to be equal to 70% whatever the distribution percentile.

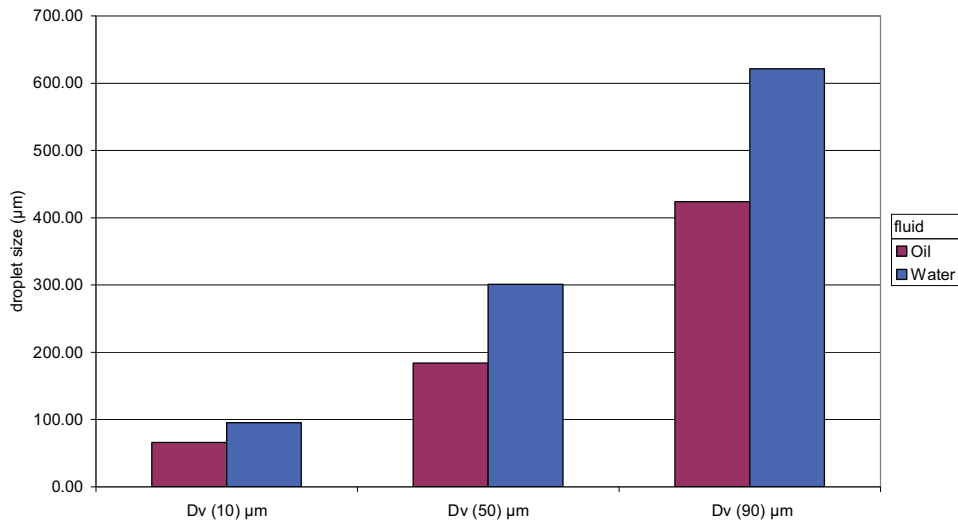


Figure 4: Droplet size indicators for water and mineral oil

### ***The effect of flow rate and spray fluid***

According to the Table 2, the effect of flow rate is quite different depending on the sprayed fluid. For water, an increase in droplet sizes is observed with increasing flow rate. In contrary, oil droplets sizes remain constant whatever the flow rates. Lower flow rate (1.3 L.min<sup>-1</sup>) induces greater droplet sizes for both water and oil.

|           | Data      |       |      |           |        |      |           |        |      |
|-----------|-----------|-------|------|-----------|--------|------|-----------|--------|------|
|           | Dv(10) μm |       |      | Dv(50) μm |        |      | Dv(90) μm |        |      |
| Flow rate | Water     | Oil   | O/W  | Water     | Oil    | O/W  | Water     | Oil    | O/W  |
| 1.3       | 81.86     | 77.76 | 0.95 | 246.20    | 203.83 | 0.83 | 583.17    | 530.73 | 0.91 |
| 4.5       | 72.61     | 60.14 | 0.83 | 227.00    | 176.40 | 0.78 | 543.60    | 398.97 | 0.73 |
| 7.5       | 97.02     | 60.61 | 0.62 | 295.37    | 177.60 | 0.60 | 605.59    | 387.53 | 0.64 |
| 9         | 114.90    | 64.83 | 0.56 | 386.18    | 177.50 | 0.46 | 713.92    | 378.50 | 0.53 |

Table 2 : Evolution of  $D_v$  and Oil/Water  $D_v$  ratio for oil and water depending on the flow rate.

Logically Oil/Water  $D_v$  ratios are decreasing with the increasing flow rate; the mean value of 70 % is then not constant.

Compared with the BCPC spray classification (Southcombe et al. 1997), droplet size indicators mainly belong to the Medium class for water and Fine class for oil.

### Spatial distribution of droplets

A spatial distribution of droplet sizes is introduced in Figure 5 for Dv50 class as an example. Similar results were found with Dv10 and Dv90 suggesting two ideas:

- Smaller droplets are concentrated in the centre for water whereas smaller droplets are mainly found at higher and lower positions for oil.
- Droplet sizes at the upper position are found to be greater than the lower position in every case whatever the fluid.

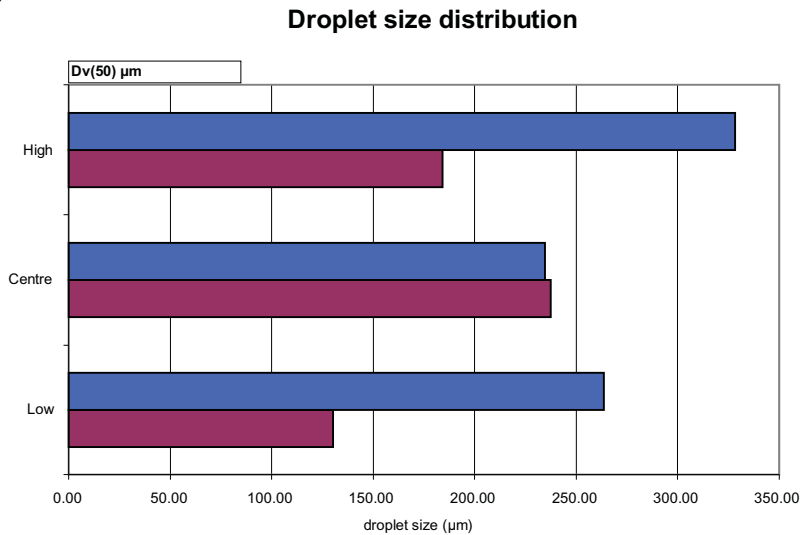


Figure 5: Spatial distribution of Droplet sizes

### 3.2. Field deposit measurements.

#### Deposit distribution.

Figures 6a and 6b show deposit patterns derived from spectrometric analysis.

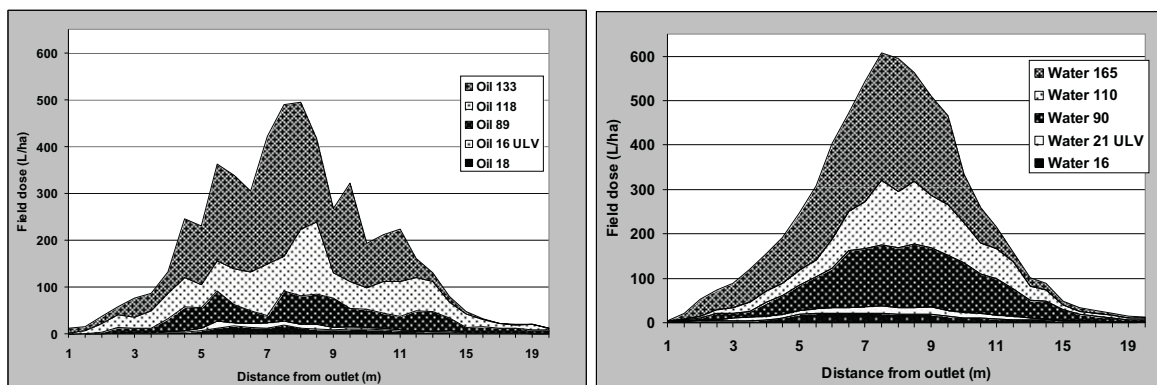


Figure 6a and 6b: Deposit pattern for Oil (left) and water (right)

In both cases, soil deposit patterns look similar with peak shape. Maximum deposit is obtained at about 8 m after the canon outlet for both oil and water.

Figure 7 shows the evolution of the collected fraction (CF) depending on the field dose for both water and oil.

The collected fraction is globally increasing with the increasing field dose starting with poor values (45 and 60 % respectively for oil and water). Maximum CF values are above 100 % suggesting some turbulence effect with additional and unexpected deposits for highest flow rates.

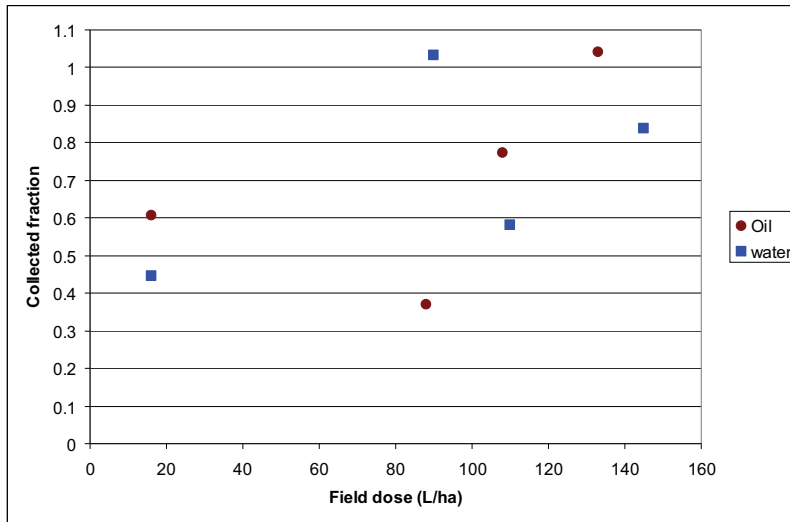


Figure 7: Collected deposit as a function of field dose for Oil and Water.

No relevant difference is observed between water and oil suggesting that differences in particle sizes do not significantly affect the efficiency of the spraying in terms of collected fraction.

### 3.3. Advection-diffusion modelling results

Figure 8 shows the ground distributions computed with the model compared with experimental data, for both water and oil spraying.  $k$  et  $D$  optimised values are given in Table 3 with the corresponding root mean square values.



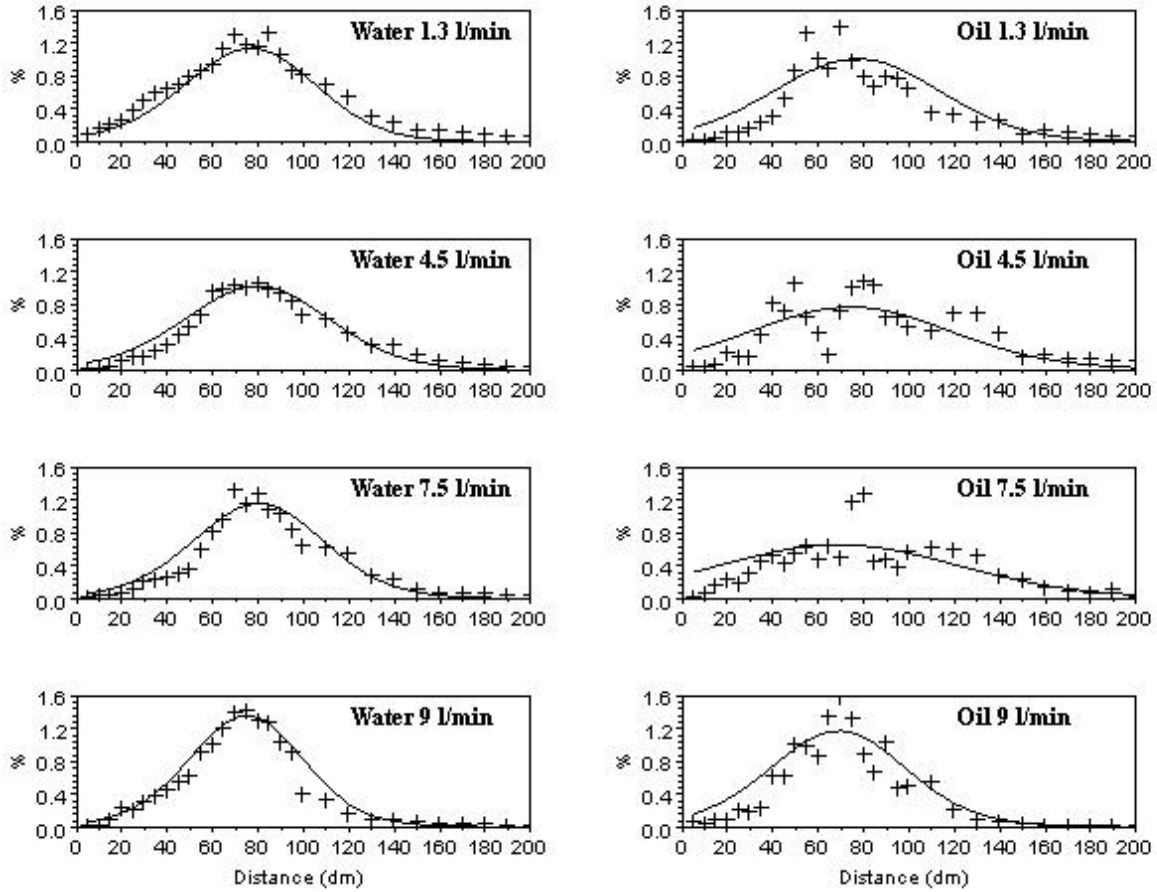


Figure 8: Computed (solid line) and measured (+) distributions obtained for water and oil spraying with several flow rates: values are given in percentage of total flow rate.

|                                   | Water   |         |         |         | Oil     |         |         |         |
|-----------------------------------|---------|---------|---------|---------|---------|---------|---------|---------|
| Flow rates (L.min <sup>-1</sup> ) | 1.3     | 4.5     | 7.5     | 9       | 1.3     | 4.5     | 7.5     | 9       |
| <i>k</i>                          | 0.9     | 1.5     | 1.5     | 1       | 0.9     | 1.5     | 1.5     | 1.5     |
| <i>D</i>                          | 2.6     | 2.8     | 2.5     | 2.2     | 3.6     | 3.8     | 4.5     | 2.5     |
| <i>R</i>                          | 4.57e-3 | 6.03e-3 | 8.01e-3 | 6.22e-3 | 11.8e-3 | 12.3e-3 | 11.6e-3 | 11.1e-3 |

Table 3: Setting parameters *k* and *D*, for advection and diffusion computation, with corresponding root mean square value.

The model gives rather good estimations for water distribution but for oil ones, errors are more important. These are mainly due to the noisy values of the measured distributions as discussed in the previous chapter. One can see that the best fitting is then obtained with large diffusion coefficients. However such fitting induce deposits before the emission point which was not observed in the field. For water, simulations give rather good results and the model can be proposed to test various other meteorologic conditions (wind, temperature and relative humidity).

Table 4 shows a comparison of measured and simulated collected fractions expressed as a percentage of the amount emitted by the mistblower.

Measured ones are obtained considering that the measured flowrate on the collectors is :  $mV/L$  where  $m$  is the amount of product collected,  $V$  is the forward speed and  $L$  is the width of the collectors.

|                                     | Water |       |       |       | Oil   |       |       |       |
|-------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Flowrates<br>(L.min <sup>-1</sup> ) | 1.3   | 4.5   | 7.5   | 9     | 1.3   | 4.5   | 7.5   | 9     |
| Computed                            | 84%   | 83.4% | 85.6% | 88.8% | 92.8% | 83.8% | 80.3% | 90.2% |
| Measured                            | 43.8% | 103%  | 57.9% | 83.2% | 59.7% | 50.3% | 74%   | 103%  |

Table 4: Computed and measured collected fractions CF (percentage of emitted flow rates)

Computed CF are generally found to be greater than measured ones. As already discussed in 3.2., experimental setup and running conditions may be suggested. On the other hand, computed data are obtained with rather rough simplifications whereas physical phenomena are not detailed. The computation model considers droplet size distributions based on distribution percentiles (e.g. Dv10, Dv50 and Dv90) extracted from experimental data (cf.3.1.). Two points can be addressed here concerning this input. First the global experimental method may be perfectible: spray should be axi-symmetric, the scanning position may interfere with the results and shall be optimally determined for each fluid. Second, data obtained in 3.1. indicated that distribution percentiles for oil may not vary depending on the flow rate. As a consequence, the model fitting is only based on the optimization of the diffusion parameter  $D$  as mentioned above.

## Conclusion

This preliminary study aims to setup methodologies for spraying quality assessment of a mist blower used with either water or mineral oil. For this purpose droplets size distributions and ground deposits were measured and discussed as quality indicators. To minimize field experiments, a simulating approach was fitted to predict ground deposits for various conditions of fluids and meteorology.

Droplet sizes described with distributions percentiles showed different behaviour depending on the sprayed fluid. Indeed increasing flow rates involved an increase in droplet size values for water while remaining constant for oil.

Ground deposits in field conditions involved quite similar distribution shapes for both oil and water. Nevertheless a great variability in the collected fraction values was observed suggesting either an important amount of losses during spraying or the need to improve experimental methodology to cope with spatial variability.

Finally, the simulation model was appropriately fitted for water distributions considering droplet sizes inputs but revealed discrepancies in terms of collected fraction with field data. However this preliminary work provides profitable bases for further simulations including a large set of experimental conditions.

Simulations of spraying distributions with oil didn't give quite satisfying results mainly due to the quality of ground deposit data as well as model fittings adjustments. Further work will mainly focus on the improvement of those last points.

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