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Assessment of the Contribute of Spray Thickeners to the Agro-chemical Drift Reduction Using a Mathematical Model and a Wind Tunnel

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Abstract

Recent researches confirm by mathematical modelling the convenience to reduce the fraction of fine droplets produced by the nozzles used for pesticide distribution on agricultural crops, in order to cut the losses of agrochemicals by drift in the environment.

A laboratory testing was carried out with the aim to investigate about the effect of spray thickeners as adjuvants; trials were conducted under controlled environmental conditions to measure spray drift with wind velocity of 1, 3 and 5 m/s and relative humidity of 30, 50 and 70%, with a temperature of 27 °C.

The results confirmed the predictions of mathematical modelling, suggesting in the meanwhile that spray thickeners are able to modify the dimensional spectrum of the population of droplets produced by the nozzles thus removing a significant part of drift prone droplets.

Keywords: Mathematical modelling, Droplet dynamics, Spray thickeners, Agrochemicals distribution, Drift, Crop protection, Environmental pollution, Wind tunnel, Agricultural engineering

1. Introduction

The physical principles, which rule the motion of water droplets in an airstream, suggest that the finest particles should be removed from the spray produced by the hydraulic nozzles in use to apply pesticides in agricultural crops, in order to reduce the agrochemical losses due to drift when spraying in windy days. The mathematical modelling of the motion of the droplets [1] confirmed this supposition.

Research into the problem of reducing spray drift during the application of pesticides [2, 3, 4 and 5] generally involves a strictly mechanical approach, thus leading to the study of the constructive and functional features of the sprayers. From this point of view, it is particularly difficult to do something on spray atomisation, since there is no type of commercial nozzle that can produce a cloud of uniform-sized droplets; instead, there is always a fraction of very fine droplets that, while contributing very little to the total volume distributed, are easily blown away by even a moderate wind.

The possibility of modifying the physical properties of water - viscosity, etc… - through the addition of spray thickeners [6], in order to reduce the fraction of very fine droplets, has also been taken into consideration.

This topic was first mentioned in the literature at the end of the 1970’s, with particular reference to comparisons between different active ingredients in terms of the effect on droplet size, but not under standard climatic conditions [7, 8, 9 and 10]; available information about their effectiveness is very limited.

In the event of an increase in the use of these products, a two-year laboratory test was set up in order to quantify the effectiveness of two adjuvants under controlled conditions, thus avoiding the effects of the climatic variability which affects the field tests; it was used a purpose-built wind tunnel placed in a temperature and humidity controlled environment.

2. Mathematical simulation of drift in wind tunnel

From a previous mathematical model [1], summarized by the subsequent equations as closed solution to the equation of dynamics under two assumptions: 1) evaporation of droplets considered negligible, due to a reduced fraction of fine particles; wind velocity w constant respect to the height inside the wind tunnel; we can write that drift x_t is equal to:

$$x_t = x^* + x_2 \tag{1}$$

where: drift x_t (m) is the horizontal distance travelled by the droplet as affected by wind; x^* (m) is the first part of drift corresponding to the transitional boundary layer around the droplet during the period t^*; x_2 is the second part of drift, corresponding to an eventual subsequent period with laminar boundary layer.

The boundary layer remains transitional along the whole height h of the wind tunnel, if the terminal vertical velocity v_{yf} is higher than the one corresponding to

Re^* = 2, namely to $v_{y*} \cong u^* = \mathrm{Re}^*/F = 2/F$; where F is: $F = \dfrac{\rho_a D}{\mu}$; u is the resultant speed accountable for the air resistance $u = \sqrt{v_y^2 + (w - v_x)^2} \cong v_y$ [1].
The vertical coordinate of the droplet trajectory is:

$$y = \frac{3b^{1/2}}{4a^{3/2}}\left[\ln\left(\frac{\left(a^{1/4}v_{yo}^{1/3} - b^{1/4}\right)\left(a^{1/4}v_{yo}^{1/3} + b^{1/4}\right)}{\left(a^{1/2}v_{yo}^{2/3} + b^{1/2}\right)}\right) - \ln\left(\frac{\left(a^{1/4}v_{y}^{1/3} - b^{1/4}\right)\left(a^{1/4}v_{y}^{1/3} + b^{1/4}\right)}{\left(a^{1/2}v_{y}^{2/3} + b^{1/2}\right)}\right)\right] + \frac{3}{2a}\left(v_{yo}^{2/3} - v_y^{2/3}\right) \tag{2}$$

where: v_{yo} is the initial speed of the droplet; D is the droplet diameter; ρ_a and ρ_l are respectively air and liquid density; μ is air viscosity; $a = \dfrac{16,5}{F^{2/3} \cdot D}\dfrac{\rho_a}{\rho_l}$; $b = \dfrac{(\rho_l - \rho_a) \cdot g}{\rho_l}$; h is height of the wind tunnel.
With $v_y = v_{y*}$, if equation (2) gives $y \geq h$, than the boundary layer is transitional along the whole height h. In this case, we will find the numerical solution $v_y = v_{yf}$ of the (2) with $y = h$. Therefore, we can subsequently obtain the total flight time t_t of the droplet:

$$t_t = \frac{3}{4a^{3/4}b^{1/4}}\left[\ln\left(\frac{a^{1/4}v_{yo}^{1/3} - b^{1/4}}{a^{1/4}v_{yo}^{1/3} + b^{1/4}}\right) - \ln\left(\frac{a^{1/4}v_{yf}^{1/3} - b^{1/4}}{a^{1/4}v_{yf}^{1/3} + b^{1/4}}\right) + 2\arctan\left(\frac{a^{1/4}v_{yo}^{1/3}}{b^{1/4}}\right) - 2\arctan\left(\frac{a^{1/4}v_{yf}^{1/3}}{b^{1/4}}\right)\right] \tag{3}$$

Instead, if the (2) gives $y = y^* \leq h$, than boundary layer becomes laminar after the point y^*, along the residual height $h - y^*$.
The flight time with transitional boundary layer is:

$$t^* = \frac{3}{4a^{3/4}b^{1/4}}\left[\ln\left(\frac{a^{1/4}v_{yo}^{1/3} - b^{1/4}}{a^{1/4}v_{yo}^{1/3} + b^{1/4}}\right) - \ln\left(\frac{a^{1/4}v_{y*}^{1/3} - b^{1/4}}{a^{1/4}v_{y*}^{1/3} + b^{1/4}}\right) + 2\arctan\left(\frac{a^{1/4}v_{yo}^{1/3}}{b^{1/4}}\right) - 2\arctan\left(\frac{a^{1/4}v_{y*}^{1/3}}{b^{1/4}}\right)\right] \tag{4}$$

The flight time t_2 with subsequent laminar boundary layer will be obtainable like a numerical solution of this equation:

$$h - y^* = \frac{B}{A}t_2 + \frac{1}{A}\left(v_{y*} - \frac{B}{A}\right)\left(1 - e^{-A \cdot t_2}\right) \tag{5}$$

where: $A = \dfrac{18}{F \cdot D}\dfrac{\rho_a}{\rho_l}$; $B = b = \dfrac{(\rho_l - \rho_a) \cdot g}{\rho_l}$.

During the first time interval 0-t^* the horizontal distance x^* travelled by the droplet is:

$$x^* = w\cdot t^* - \frac{w}{a\cdot v_{ym}^{1/3}}\left(1-e^{-a\cdot v_{ym}^{1/3}\cdot t^*}\right) \tag{6}$$

where v_{ym} is the mean speed along y-axis during the first time interval 0-t^*: $v_{ym}^{1/3} = \frac{v_{y0}^{1/3}+v_{yf}^{1/3}}{2}$.

The subsequent period, with the laminar boundary layer, begins as time t^* is elapsed. At a time $t_2 = t_t - t^*$, calculated by the (5), the distance x_2 travelled during the second period for $\mathrm{Re} \le 2$ is:

$$x_2 = w\cdot t_2 - \frac{\left(w - v_{x^*}\right)}{A}\cdot\left(1-e^{-A\cdot t_2}\right) \tag{7}$$

Referring to the bigger droplets (D > 200 μm), the time t^*, is greater than the total flight time t_t. Therefore, the second period with laminar boundary layer will be absent and the value of drift results from an equation similar to the (6):

$$x_t = w\cdot t_t - \frac{w}{a\cdot v_{ym}^{1/3}}\left(1-e^{-a\cdot v_{ym}^{1/3}\cdot t_t}\right) \tag{8}$$

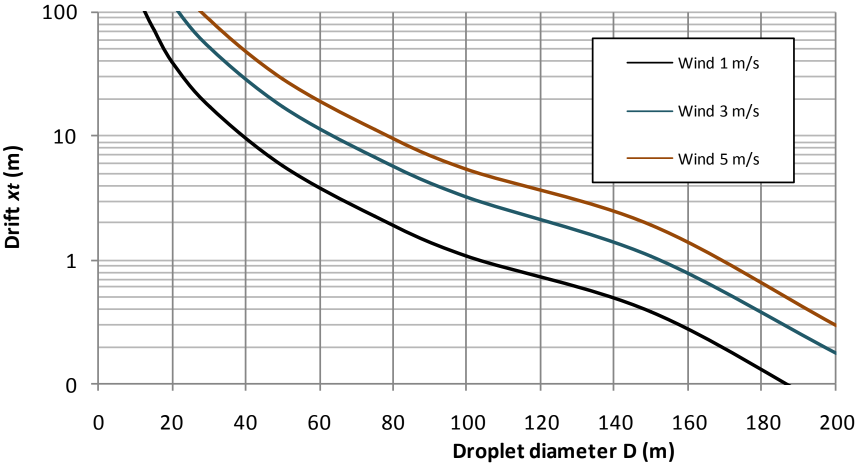

Fig. 1 Drift vs. droplet diameter and wind speed

As results from the mathematical simulation using the previous mathematical model [1], summarized by the equations just presented, figure 1 shows that a 80 μm droplet diameter evidences a drift distance smaller than 10 m even when wind velocity is as high as w = 5 m/s.

Mathematical simulation, therefore, suggests reducing, in the droplets population as emitted from the nozzles, the fraction of particle having diameter smaller than 80÷90 μm. This endorses the opportunity of an experimental verification, using the wind tunnel as in the present work, of the spray drift reduction by modifying the droplet diameter through an increase of fluid viscosity: biodiesel in [11] and [12]; in this case water used to dilute agrochemicals, by adding some chemical adjuvants (thickeners).

3. Experimental evaluation of drift reduction

3.1 Materials and Methods

The research here reported aimed to validate experimentally the mathematical simulation of droplets drift as affected by adding two different spray thickeners to water, without the effects of the variable climatic conditions that affect field tests.
The trials were carried out under controlled conditions using a wind tunnel built inside an air-conditioned building were temperature could be kept constant 27 °C. To ensure that temperature and humidity remained constant, the laboratory (1,800 m^3 volume), was equipped with a 250,000 kJ air heating device and a humidifier.

The tunnel measures were 8 x 0.8 x 0.8 m (L x W x H); airflow came from a fan placed at one end of the tunnel. To measure and record wind speed at nozzle height, a digital anemometer was used. Water was supplied at 3.5 bar by a pressurised 25 dm^3 tank with supplementary agitation by an auxiliary pump; it supplied a 80° flat fan nozzle (*Teejet* XRB 002VS), placed 50 cm above the tunnel base, 2.10 metres from the outlet and 4 metres from the fan, with an anti-drip system and a filter. Pressure was monitored using a digital manometer.

The trials of the *first year* considered a polyacrylamide-based adjuvant (AgRHO DR2000® by Rhône Poulenc, New Jersey); several spraying sessions (duration one minute) were made in the tunnel and the liquid collected in each session was weighed to relate it to the amount of liquid collected without wind. The ratio between the two measurements gave the drift, expressed as percentage.

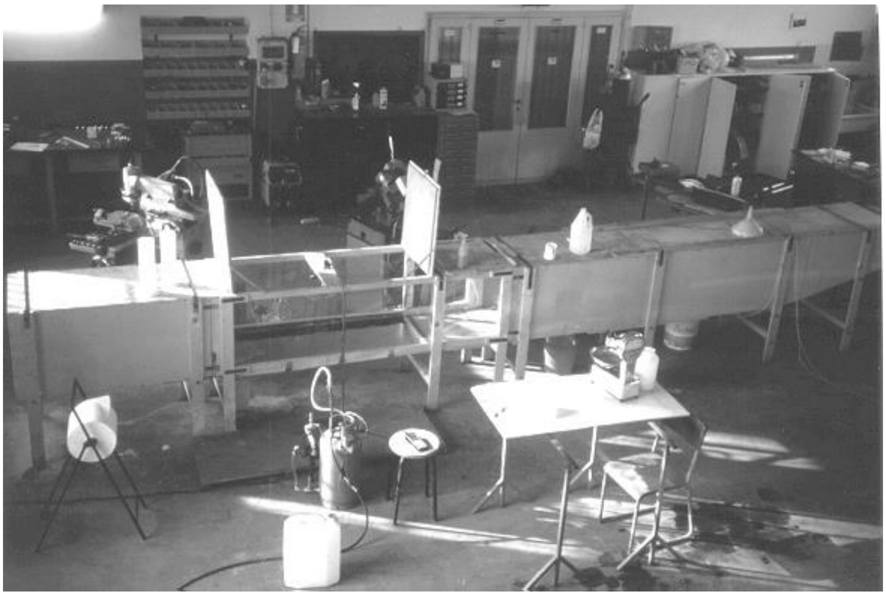

Fig. 2 Overview of the wind tunnel

Temperature was kept to 27 °C, while humidity was set to three levels (30, 50 and 70%); for each level, four wind speed conditions (0, 1, 3 and 5 m/s) were tested with three replications.

During the *second year,* a comparison was made with another polymeric-based adjuvant, Define® by Becker-Underwood (Iowa, USA). The test was run with temperature of 26 °C and relative humidity 60%. In this case, with the aim to assess drift by measuring the deposit downwind, the tunnel was lengthened in order to allow to position samplers at rising distances up to 6 m from the nozzle. This has been mounted on a movable carriage installed over a cross-section of the tunnel, 2 m long and 0.65 m wide. The nozzle crossed the tunnel with a speed of 0.18 m/s, thus allowing the jet to run across the airstream. The analysis of the deposit was carried out by colorimetry, using a yellow tracer (Tartrazine 1%). For the sampling a set of four Petri boxes (diameter 150 mm) were used.

At the end of the experiment, a trial was included to evaluate any phytotoxicity of the tested product on potted cucumber and tomato plants; this was because of the fact that one of the active ingredients – polyacrylamide – is itself a toxic molecule. The trial was divided into the following 5 treatments of 96 plants each:

- control treated with water alone
- fungicide
- fungicide + drift retardant
- insecticide
- insecticide + drift retardant

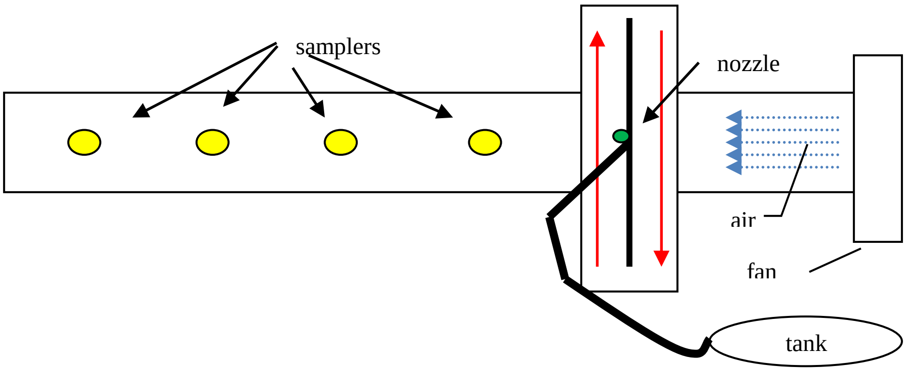

Fig. 3 Layout of the tunnel setup

The plants were sprayed in the laboratory on a moving mat 1.5 m in length, at a simulated distribution volume of 250 dm^3/ha, with a fungicide (*Cimoxanil*, 2 g/dm^3) and an insecticide (*Acephate*, 4 g/dm^3). During the second year the trial was repeated in open field with different amounts of liquid sprayed per surface unit (200, 400, 600, 800 dm^3/ha). The trial lasted until harvest with periodical controls.

3.2. Results

First year

As mentioned above, the trials were carried out under a mean temperature of 27°C and 3 levels of relative humidity (30, 50 and 70%); 4 wind velocities were tested (0, 1, 3 and 5 m/s), with three replications for each test. The percent loss by drift for each replication was computed by weighing the liquid sprayed during 1 minute, and relating it to the amount collected without wind as follows:

$$L = \frac{m_o - m_n}{m_o} \cdot 100 \qquad (9)$$

where: L is the amount of liquid lost (%); m_o is the mass of liquid (g) collected with wind speed = 0 m/s; m_n is the mass of liquid (g) collected with wind speed =n (m/s).

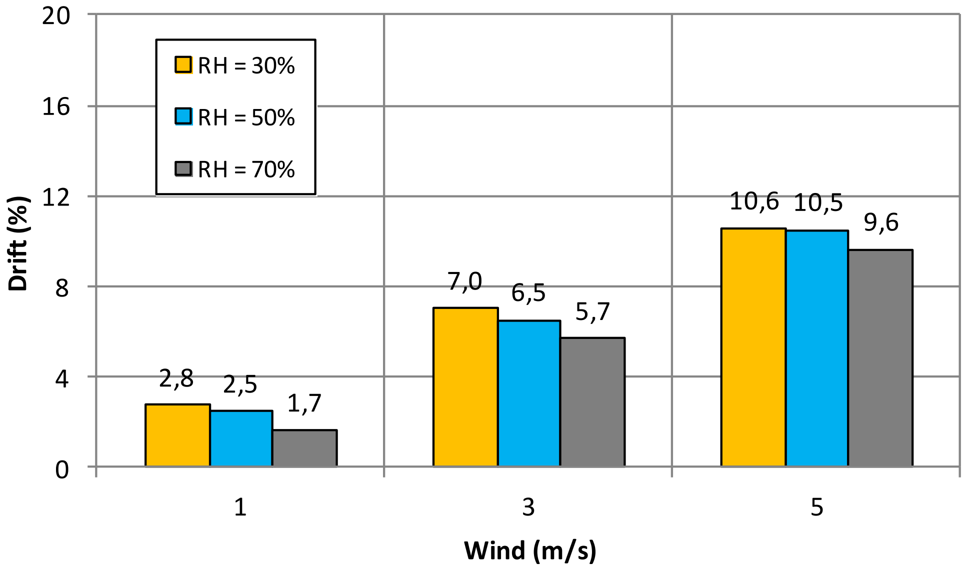

Fig. 4 Loss by drift L (%) vs. wind velocity w (m/s) and relative humidity RH (%) found by using the adjuvant

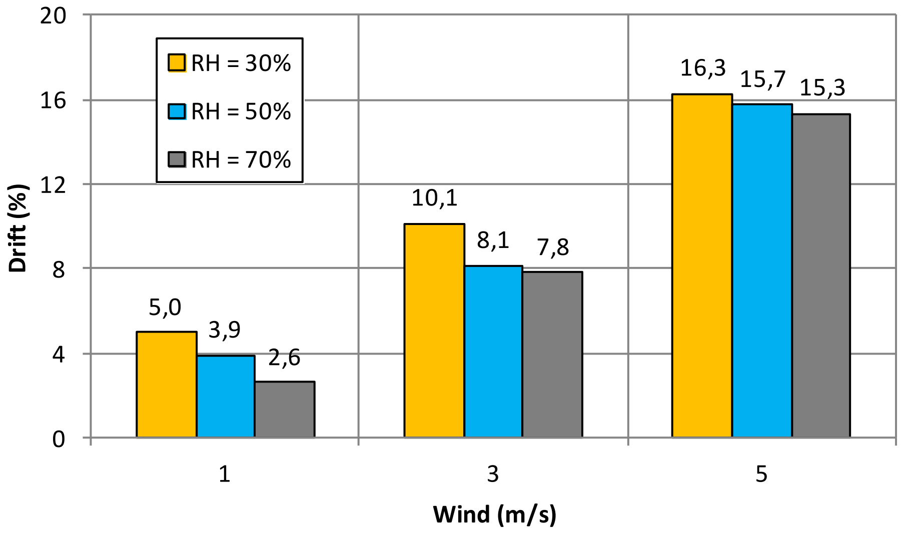

Fig. 5 Loss by drift *L* (%) vs. wind velocity *w* (m/s) and relative humidity *RH* (%) found using only water

As shown in figures 4 and 5, the best efficiency of the adjuvant occurs with lower humidity and lower wind velocity (drift -44% at 27°C, RH 30% and *w* 1 m/s, see also tab. 1); overall, the chemical adjuvant resulted significantly effective in all the tests.

		R.H %		
		30	50	70
Wind (m/s)	1	44	36	35
	3	31	20	27
	5	35	33	37

Tab. 1 Global effectiveness of AgRHO DR2000: summary of the results of the first year (percent drift reduction)

Second year

As mentioned earlier, it was intended to compare the adjuvant used during the first year with another one, assessing the deposit distribution downwind along the surface of the tunnel. Four samplers were positioned on the tunnel floor, 1.5 m far from each other, as shown in fig. 3.

After the spraying, the samples were dried, washed with 10 ml water and read with a UV/Vis spectrophotometer. The ratio of the absorbance of samples to the absorbance of the sprayed solution allowed to determine the concentration of the sample and then, as the collector's area was known, to determine the deposit of tracer for surface unit.

As shown in fig. 6, the adjuvant AgRHO DR2000 has confirmed the results of the first year. In all the tests, the other adjuvant was less effective, even if it has reduced the total drift respect to water. The deposit on ground resulted lower with both the adjuvants; only with 3 m/s wind speed, Define has revealed a higher deposit respect to water (+7%), while at 1 m/s and 5 m/s the deposit is resulted lower of 27% and 14% respectively. AgRHO DR2000 confirmed the good results of the first year, reducing drift of 42%, 10% and 37% at 1, 3 and 5 m/s wind speed respectively. At the lowest wind velocity, the deposit resulted uniformly distributed along the tunnel. As in the first year, both the adjuvants have shown a better effectiveness at wind speed 1 and 5 m/s than 3 m/s, thus confirming the results of the first year and the validity of the mathematical simulation.

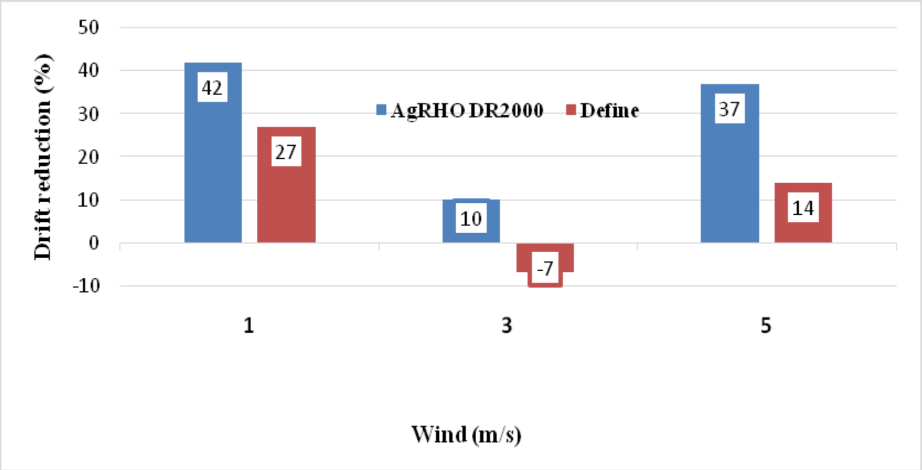

Fig. 6 Effect of the two adjuvants on the reduction of drift respect to water

Effect on atomisation

Another simple test was made to verify the effect of the adjuvants on the formation of the droplets. As their common name explains, the spray thickeners determine the reduction of the fraction of finest droplets (diameter less than 80÷90μm). To verify this, some water sensitive papers were sprayed with the three solutions. As fig. 7 shows, both the adjuvants affected the spray causing a coarser atomisation; an instrumental evaluation of the droplets diameters distribution was not made, but it is evident that the papers sprayed with the spray thickeners contain more large droplets then the one sprayed with water alone. This aspect is worth considering when using adjuvants for applications that require an accurate coverage of the treated surface, and will be investigated through field tests.

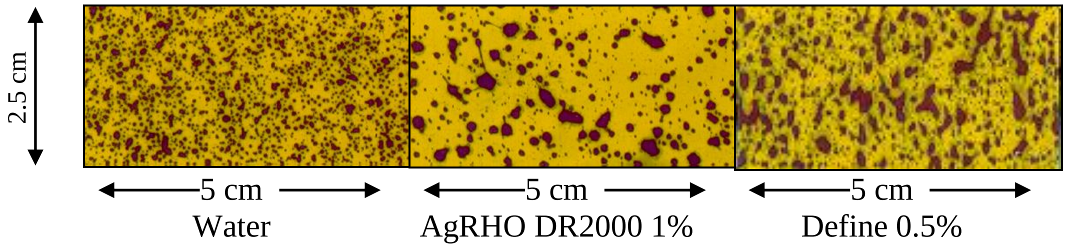

Fig. 7 Effect of the spray thickeners on the atomisation of spray

Trials of phytotoxicity

The tests revealed no visible phytotoxicity, neither in greenhouse nor in open field.

4. Conclusions

Based on the results some considerations can be drawn.

First, the analysis of the data collected indicates that the two different methods of assessing drift used during the two years gave comparable results in the trials run under similar conditions. This confirms also the validity of the colorimetric technique for the quantitative assessment of drift.

Both the adjuvants resulted effective respect to water even if in a different way: AgRHO DR2000 resulted more effective with higher wind speed, while Define had a slightly better action with lower wind speed, reducing the deposit over 4 m far from the nozzle.

Both the adjuvants presented a clearly visible effect on the spray atomisation; the fraction of fine droplets is reduced, while an increase of large droplets on the sprayed water sensitive surface is evident. This could represent a limit for the use of the adjuvants in some applications, which require an accurate coverage of the target, but should not be important in the cases in which this coverage is not required, such as for herbicide applications or foliage spraying with systemic active ingredients. Anyway, this aspect needs a separate investigation.

At last, the trials showed no phytotoxicity, neither in greenhouse nor in open field.

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