Droplet sizing of agricultural sprays, comparing PDA and Shadowgraphy

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Summary

Experiments were carried out to compare Phase Doppler Anemometry (PDA) and Shadowgraphy in determining droplet size distributions of spray nozzles. Additional experiments involved the use of a spray liquid that contained a surfactant which could enhance droplet sizes. When venturi-type nozzles were used, the air that was sucked in to the nozzle could end up as bubbles in the larger drops. PDA appeared to misinterpret the size of such drops, leading to a drop size distribution of a seemingly finer spray. Shadowgraphy might produce better results in such cases, although appropriate and accurate image processing is an issue that requires further attention.

Introduction

In spray drift research in agriculture, the emission of pesticide sprays (spray drift) strongly depends on the type of spray nozzles used. In various EU countries the authorized use of agricultural spray nozzles is regulated by classifying nozzle types according to their drift-reducing capabilities, compared to a certain reference nozzle type. A major aspect of a nozzle type is its drop size distribution in relation to the liquid pressure applied. A well-known and proven method to measure drop size distributions is phase-doppler anemometry (PDA). However, PDA implicitly assumes that drops are spherical, homogeneous and (preferably) transparent. This is not always the case, which may lead to misinterpretation of the data signals measured with PDA. For instance, to reduce the amount of spray drift, various nozzle types are manufactured such that they produce relatively large spray drops. Sphericity of large drops usually is not assured. In other cases, drift-reducing adjuvants (drift retardants) could be added to the spray liquid. Typically, such drift retardants tend to produce larger drops, not only causing problems regarding (lack of) sphericity, but these drops may also contain small air bubbles inside the drops. Such drops cannot be considered homogeneous.
A particle imaging technique such as 'Shadowgraphy' may overcome some of the shortcomings of PDA, as particle sizing is much less sensitive to non-sphericity and inhomogeneity of the droplets (e.g. Sijs et al. 2021). To be able to use drops size information of spray nozzles in other projects, results from PDA and Shadowgraphy should be interchangeable, ideally. In this preliminary study PDA and Shadowgraphy are compared in various experiments with different nozzle types, with a few different spray liquids.

Methods

In our experiments, for PDA a phase-doppler particle analyzer (PDPA; TSI) is used. It measures drop size and velocity (1D) for drops one by one, when they pass a small cross-sectional area of two laser beams. Frequency and phase shifting of scattered light are interpreted as droplet velocity and size.

Our Shadowgraphy equipment (TSI) is a 2D imaging technique where laser flash photographs are analysed for drop size and velocity. Drops show up as dark spots ('shadows') against a bright background. In principle the shape of the drops is rather irrelevant, similar as the interior of the drops (i.e. inhomogeneity is not a big problem). Therefore, Shadowgraphy can be used in situations where PDA may not give adequate results.

In a first experiment, BCPC threshold nozzles (Southcombe et al., 1997) were measured using both PDPA and Shadowgraphy. The resulting drop size distributions were compared. A second experiment, using PDA, involved four nozzle types that were tested with two spray liquids: tap water and a solution of a drift-retardant adjuvant (surfactant) in tap water. The latter is anonymized as 'test liquid #1'. Drift-retardant adjuvants tend to coarsen the spray and therefore may lead to a decrease of spray drift. Two of the nozzle types use the venturi effect to suck in air into the nozzle body, producing coarser sprays while flow rates remain moderate. Droplets produced by such nozzle types may contain air bubbles. In a third experiment, using Shadowgraphy, a (different) test liquid (#2) was used, also a solution of a drift-retardant adjuvant in tap water. The venturi-type nozzle type Albuz CVI 80-025 (at 3 bar liquid pressure) was selected to investigate the effects of test liquid #2 compared to tap water.

Spatial vs temporal distributions

Typically, measuring techniques related to particle flow through a cross-sectional area result in so-called temporal particle size distributions, while imaging techniques 'freeze' the drops in space and give so-called spatial size distributions. These distributions are linked to each other by the velocity of each individual droplet. PDA produces a temporal drop size distribution, while Shadowgraphy gives a spatial distribution. To compare results of PDA and Shadowgraphy in a valid way, the spatial size distributions of the latter are transferred to temporal distributions weighted by the velocity of each droplet.

PDA and Shadowgraphy measurements, BCPC threshold nozzles

The BCPC nozzle classification system (Southcombe et al., 1997) can classify nozzles according to their spray quality as very fine (VF), fine (F), medium (M), coarse (C), very coarse (VC) and extra coarse (XC). In this classification system, threshold nozzles are defined at the boundaries between these classes. Fig.1 shows (temporal) drop size distributions for the BCPC-VF/F threshold nozzle (LF 110-01, 4.5 bar) and the BCPC-M/C threshold nozzle (Lechler LU 120-06S, 2.0 bar), for PDPA and Shadowgraphy. These measurements appear to indicate that Shadowgraphy tends to result in larger droplet sizes than PDPA.

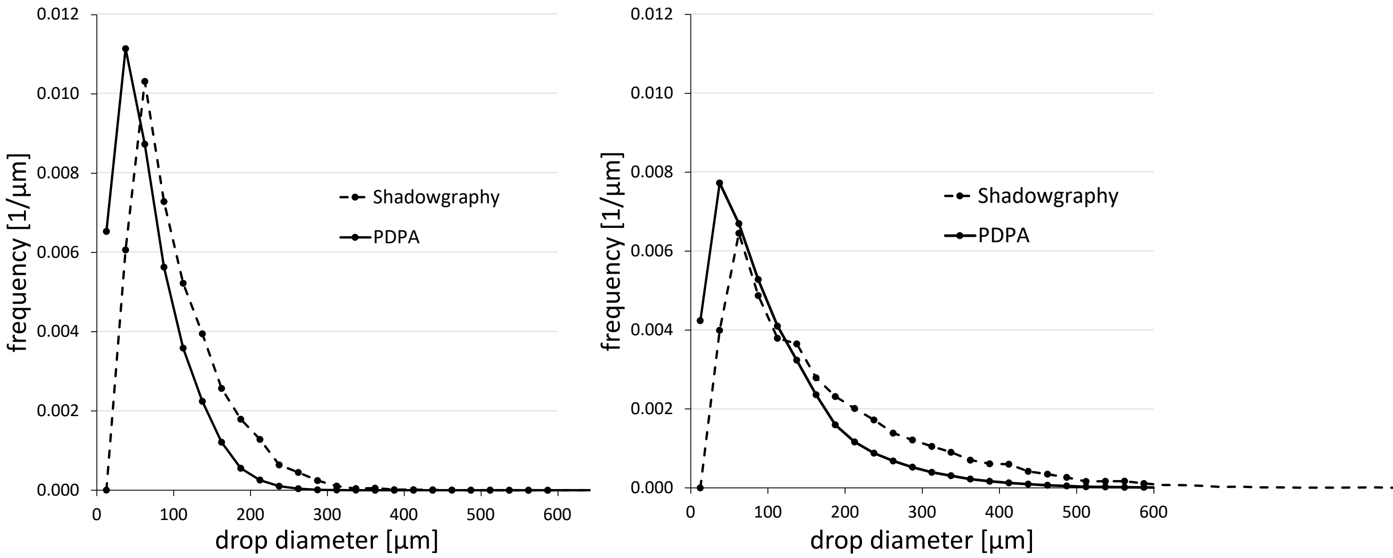

Fig.1 Drop size distributions determined using PDPA and Shadowgraphy; left: BCPC-VF/F nozzle; right: BCPC-M/C nozzle.

PDA measurements, test liquid #1

Drop size distributions were measured with PDPA for four nozzle types, for water and test liquid #1 (See Table 1). The volume fraction of drops smaller than 100 µm, V_{100}, is an important parameter to give a reasonable estimate of the amount of spray drift in agricultural spray applications. Fig.2 shows Volume Median Diameter (VMD) values and V_{100} values for the mentioned nozzle types with water and test liquid #1. V_{100} is not the only parameter involved in estimating spray drift, but in a first rough approach spray drift approximately is proportional to V_{100}. In that approximation, the additional drift reducing potential (R) of the test liquid can be defined as follows:

$$R = 100\% \cdot (1 - V_{100,testliq}/V_{100,water}) \quad (1)$$

Table 1 shows measured V_{100} values for tap water and test liquid #1 together with the corresponding factor R. For test liquid #1, the values of V_{100} are lower than those for water, showing that the drop size distributions have become coarser. However, the additional drift reducing potential R appears to be much lower for the venturi-type nozzles than for the first two nozzle types.

Table 1. Nozzle types and pressures tested with PDA. Measured $V_{100,W}$ (tap water) and $V_{100,1}$ (test liquid #1); R is the corresponding drift reducing capacity by the test liquid.

	Nozzle type	Pressure [bar]	Group	Flow rate [L/min]	$V_{100,W}$ [%]	$V_{100,1}$ [%]	R [%]
1	Teejet XR 11004	3	Standard	1.6	4.09	2.46	40
2	Teejet DG 11004	3	Pre-orifice	1.6	2.55	1.17	54
3	Lechler ID 12002	3	Venturi	0.8	0.74	0.62	16
4	Agrotop TDXL 11004	3	Venturi	1.6	0.66	0.48	27

GALA e.V., Karlsruhe, Germany, ISBN 978-3-9816764-9-5

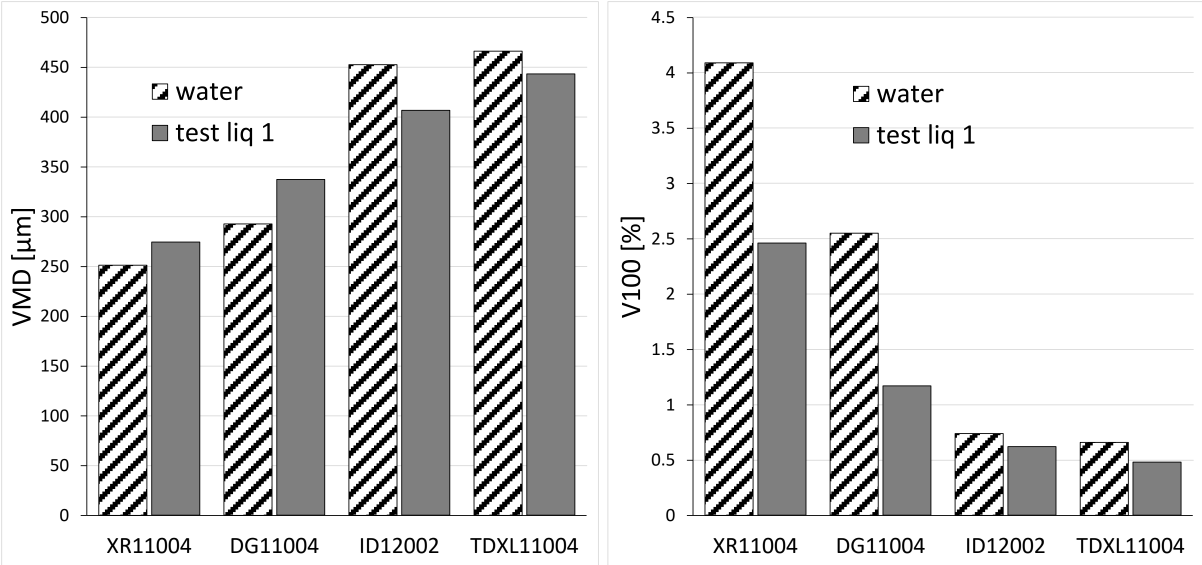

Fig.2 Left: VMD for 4 nozzle types and 2 liquids; right: corresponding V_{100} fractions. Measured with PDPA.

Relative flow rate check

PDA measures drops at the small cross-section of two laser beams. From the measured drop size distribution the volume mean diameter D_{30} can be derived. This is the diameter of a drop of average volume, V/N, where V is the total spray volume measured and N is the corresponding number of drops. When N drops are measured in time t, then the flow rate Q of spray passing through the measurement cross-sectional area is given by:

$$Q = \frac{1}{6}\pi \, {D_{30}}^3 \; N/t \qquad (2)$$

NB this Q is not the nozzle's actual flow rate, but only representing the part of the spray that is measured by the PDA equipment. In principle, Q is proportional to the full flow rate of the nozzle and related to the ratio of the cross-sectional area at the laser beam intersection and that of the whole spray cone (at the height of measurement). This implies that Q should be independent of drop size distribution, as far as top angle of the spray cone does not change. Consequently, a comparison of Q values (e.g. for different spray liquids) can be used to check whether drops are misinterpreted or discarded. Table 2 gives the computed values of Q for the tested nozzles and spray liquids, together with the ratio Q_1/Q_W. For the nozzle types 1 and 2 the ratio is close to 1. For the venturi-type nozzle types 3 and 4 the ratio is much less than 1, indicating that not all droplets are measured correctly for test liquid #1.

Table 2. Cross-sectional flow rates in PDPA measurements for water (Q_W) and test liquid #1 (Q_1); and their ratio.

	Nozzle type	Q_W [mm^3/s]	Q_1 [mm^3/s]	Q_1/Q_W
1	XR 11004	0.353	0.347	0.98
2	DG 11004	0.325	0.360	1.11
3	ID 12002	0.145	0.083	0.57
4	TDXL 11004	0.307	0.194	0.63

Nozzle types 1, 2 and 4 are of size ‘04’, which means that their full flow rates are equivalent (when measured at the same liquid pressure), see Table 1 for nozzle flow rates. Nozzle type 3 has size ‘02’, which has a flow rate which is half of that of the ‘04’-nozzles. The cross-sectional flow rates for water in Table 2 indeed indicate such approximate relationships; see also Fig.3.

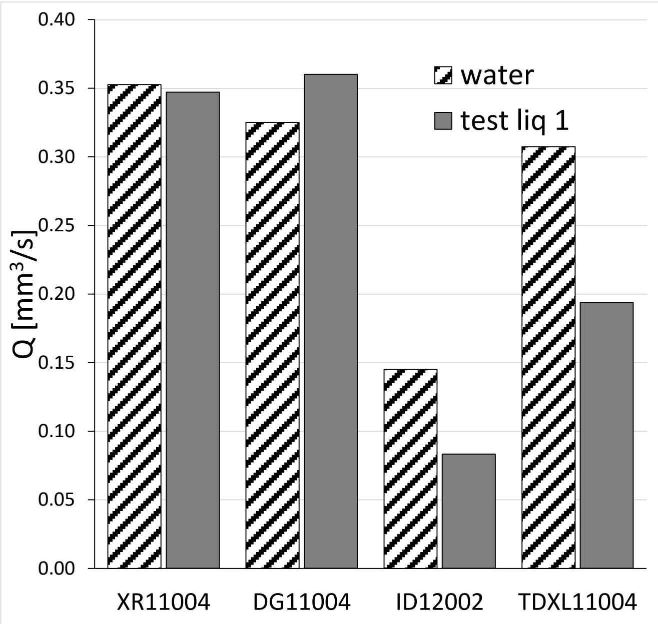

Fig.3 Cross-sectional flow rates (Q) for four nozzle types and two liquids, at 3 bar liquid pressure. Derived from PDPA measurements.

Shadowgraphy measurements, test liquid #2

Three nozzles of type Albuz CVI 80-025 were measured three times, giving 9 separate drop size distributions. The average results of VMD and V_{100} are shown in Table 3. The additional drift reducting potential of test liquid #2 is 38% in this case.

Table 3. Average VMD and V_{100} from Shadowgraphy measurements of drop size distributions for Albuz CVI 80-025 at 3 bar; with tap water and test liquid #2.

Liquid	VMD [µm]	V_{100} [%]	R [%]
Water	503	0.26	-
Test liq #2	696	0.16	38

Example images from the centre of the spray, 30 cm below the nozzle outlet, are shown in Fig.4. The picture on the left-hand side shows the water spray, on the right-hand side the test liquid #2. The water drops appear to be homogeneous, while several drops of test liquid #2 contain air bubbles.

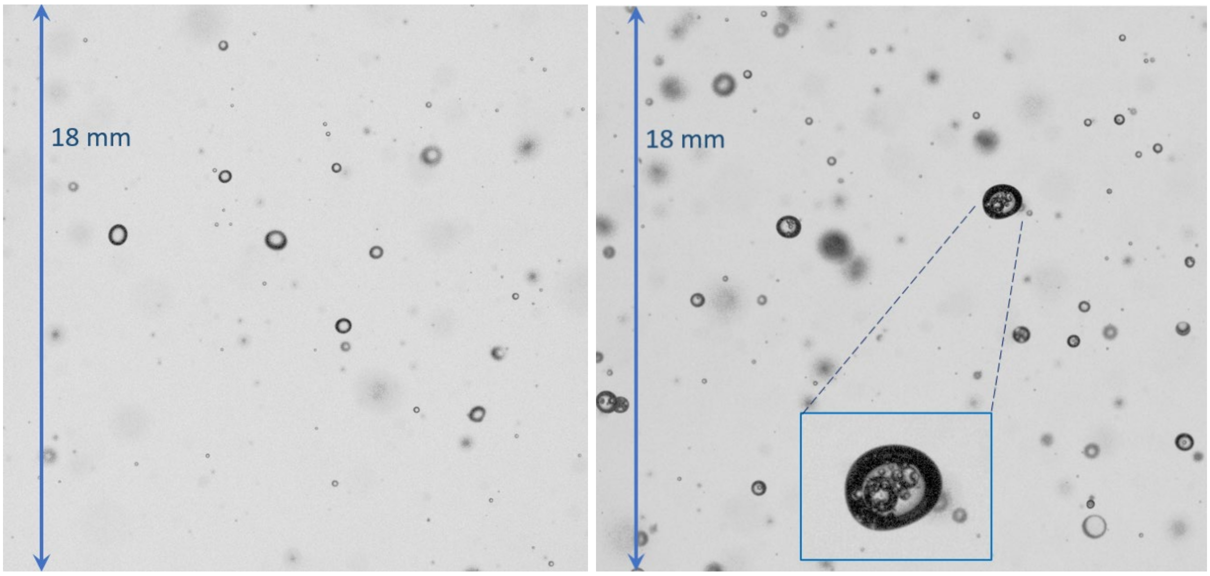

Fig.4 Example pictures of spray of water (left-hand side) and test liquid #2 (right-hand side), at about 30 cm below the nozzle outlet (Albuz CVI 80-025). The test liquid clearly shows several drops with air bubble inclusions.

Discussion

In the comparison of drop size distributions for BCPC threshold nozzles, the Shadowgraphy results show fewer small drops and more larger drops than PDPA. In another comparison (Sijs et al., 2021) such differences were less pronounced. Unfortunately, signal processing in PDPA is a kind of 'black box', and an independent validation of the results compared to the real drop sizes is not easily done. On the other hand, in Shadowgraphy realistic 2D images of droplets are produced, which were expected to be interpreted more easily. However, results appeared to depend significantly on the filter settings during image processing, particularly regarding the sizing of drops that were slightly out-of-focus. This has to be fine-tuned further. In our current optical setup with Shadowgraphy, the smallest detectable droplet diameter was about 35 µm (3 pixels wide), while our PDPA system could determine drop sizes down to 13 µm. However, this can only partly explain the observed differences between PDPA and Shadowgraphy.

In the PDA measurements with test liquid #1, Fig.2-left shows that for the first two nozzle types the test liquid tends to coarsen the spray (i.e. showing a higher VMD), while for the venturi-type nozzles the spray seems to become finer (lower VMD). However, Fig.2-right shows that for all nozzle types V_{100} decreases with test liquid #1, supporting a coarser spray in all cases. Table 2 shows that for the venturi-type nozzles a significant part of the spray seems to be missing when test liquid #1 is used. These results suggest that test liquid #1 coarsens the spray for any nozzle type but part of the larger drops probably are misinterpreted as small ones or discarded completely, when venturi-type nozzles are used.

The Shadowgraphy measurements were carried out with a different venturi-type nozzle and a different test liquid (#2). Images of droplets indeed show that air bubbles may occur in larger drops produces by venturi-type nozzles, when the spray liquid contains a surfactant. It is likely that PDA cannot measure the correct size of such inhomogeneous drops, leading to effects described above for test liquid #1, such as reduced flow rates and low R values.

Conclusion

Shadowgraphy appears an attractive technique for droplet sizing to replace or complement PDA measurements, particularly in situations where PDA may not produce adequate results, such as when the spray liquid contains a surfactant. However, the image processing procedure requires an accurate adjustment of the imaging filters. Particularly, blurred out-of-focus droplets could be easily oversized or undersized when the filters are not set appropriately. The difference in smallest detectable drop size appears to have only a minor effect on the size distribution. Further investigation is needed to show how PDA and Shadowgraphy may support each other. The observed differences must be understood before the techniques can be used interchangeably.

Literature

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