A chamber for scanning spray from agricultural nozzles using an Aerometrics phase/doppler particle analyzer

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Wolf, T.M., Stumborg, M., Caldwell, B.C. and Grover, R. 1995. A **chamber for scanning spray from agricultural nozzles using an Aerometrics phase/doppler particle analyzer**. Can. Agric. Eng. **37**:305-310. The Aerometrics Phase/Doppler Particle Analyzer (PDPA) is a laser based particle analyzer capable of non-intrusive measurement of the droplet diameter and velocity of a variety of sprays. A chamber suitable for three dimensional scanning of sprays produced by agricultural nozzles, as well as for safe handling of pesticides, is described. The chamber, constructed entirely of corrosion-resistant materials, contains a computer controlled three-dimensional traversing system for moving the nozzle, glass walls and a sump for collecting the spray liquid, air ventilation for removing vapours, a liquid delivery system capable of monitoring flow rate and pressure, and a wash-down nozzle for removing pesticide residues. Evaluation of the PDPA system in conjunction with the chamber, using tap water as the spray solution, indicated the following: a) there was good overall measurement consistency of the PDPA system from day to day; b) the glass walls of the chamber reduced PDPA laser beam intensity, resulting in decreased sensitivity for small droplets; and c) the presence of the fan induced downdraft in the chamber increased average droplet velocity and increased the number of small droplets detected. In all cases, observed effects were minor and were not considered to be of practical significance with respect to the PDPA's accuracy.

L'appareil Aerometrics Phase/Doppler Particle Analyzer (PDPA) est un analyseur de particules au laser qui permet la mesure du diamètre et de la vitesse des gouttelettes en pulvérisation. Une chambre de pulvérisation pour l'analyse tridimensionnelle des jets émis par des buses de pulvérisateurs et permettant une manipulation sécuritaire des produits pesticides a été développée et utilisée en conjonction avec cet appareil. Construite en matériaux résistant à la corrosion, cette chambre est dotée d'un système contrôlé par un ordinateur qui régit les déplacements de la buse. On y retrouve également les périphériques nécessaires pour: la mesure du débit et de la pression du liquide pulvérisé, l'évacuation des vapeurs, la collecte des liquides pulvérisés ainsi qu'un système de nettoyage. L'évaluation de l'appareil PDPA et de la chambre de pulvérisation en utilisant de l'eau a montré que: a) les mesures obtenues avec le PDPA étaient consistantes d'une journée à l'autre; b) les murs vitrés de la chambre de pulvérisation réduisaient l'intensité du faisceau laser du PDPA et par conséquent la sensibilité du système pour les petites gouttelettes; et c) l'écoulement descendant induit par le ventilateur dans la chambre a augmenté la vitesse moyenne des gouttelettes de même que la quantité de petites gouttelettes détectées. Dans tous les cas, les effets observés étaient mineurs et n'affectaient pas la précision du PDPA de façon significative.

INTRODUCTION

The ability to accurately determine the droplet size spectra produced by agricultural spray nozzles is an invaluable aid in the study of application technology. Droplet size can affect uptake and translocation of herbicides (Wolf et al. 1992) and both droplet size and velocity have important implications in drift (Threadgill and Smith 1975; Johnstone 1978), interception (Spillman 1984), and retention (Lake 1977; Merritt and Taylor 1978) of herbicidal sprays. The Aerometrics Phase/Doppler Particle Analyzer (PDPA) (Aerometrics Inc. Sunnyvale, CA) is a unique instrument which utilizes the light scattered by spherical particles to obtain simultaneous size and velocity measurements (Bachalo and Houser 1984). This system permits temporal and spatial non-intrusive measurements of a variety of sprays with high speed and accuracy.

To facilitate analysis of sprays from agricultural nozzles with a PDPA unit, a sophisticated spray chamber was designed, constructed, and evaluated. The objectives of this study were a) to describe the PDPA unit and the chamber designed for it, and b) to test the performance of the PDPA in terms of i) daily measurement fluctuations, ii) effects of spray confinement within the glass walls of the chamber, and iii) effects of air down draft on droplet size and velocity measurements.

MATERIALS AND METHODS

Phase/Doppler Particle Analyzer (PDPA)

The PDPA, first described by Bachalo and Houser (1984), consists of five major components: a transmitter, a receiver, a signal processor, a motor control module, and a computer. The transmitter generates a laser beam, splits it into two equal intensity beams, and focuses them to an intersection point which forms the measurement region (sample volume) within the spray pattern. Optical components within the transmitter serve to focus, partition, and collimate the laser beam. The motor controller allows the user to control optical components within the transmitter unit via software. The receiver converts optical signals to electronic impulses which are then analyzed by the signal processor. The computer provides a user interface through software. Lefebvre (1989) has described and compared this instrument with other commercially available laser droplet sizing technologies.

Normal operation of the transmitter requires the user to select three hardware parameters: the laser beam spacing, a collimating lens, and a transmit lens. The described system allows three beam spacings and contains two collimating lenses (160-mm and 300-mm focal lengths) and three transmit lenses (200-mm, 495-mm, and 1016-mm focal lengths). Combinations of collimating and output lenses as well as beam separations provide a total of 18 optical configurations to accommodate a large range of particle sizes that may be measured. Measurable droplet size range is from 0.5 to 1020 µm. The ultimate size range measurable at one setting (i.e., the ratio of largest to smallest particles) is 35.

When a particle passes through the intersection of the two beams, scattered light produces an interference fringe pattern that contains information on the particle size and velocity. Detectors at the back of the receiver unit measure and validate the signals produced by the fringe pattern. The user controls the photomultiplier tube (PMT) voltage that determines the sensitivity of the detectors through the system software. A complete temporal description of the spray drop distribution, which includes volume median diameter, number median diameter, arithmetic mean, volume mean, sauter mean, velocity mean, size-velocity correlation, and other parameters is possible through the software. Some parameters can be expressed using spatial reduction. Graphical output of measured data is available and raw data can be exported to other software.

Spray chamber construction

A laboratory spray chamber was designed to facilitate the analysis of agricultural nozzle spray patterns with the PDPA (Fig. 1). The chamber was constructed to allow discharge of formulated herbicide/water mixtures in a controlled laboratory setting to facilitate the fast and accurate accumulation of nozzle discharge data.

Minimum laboratory space requirements for operation of the spray chamber were 3 m x 3.75 m, with a 2.4 m ceiling. The spray chamber has the following features: it is constructed of chemically resistant or inert components able to withstand agricultural herbicides; it is geometrically suited to the requirements of the Aerometrics PDPA laser doppler particle analysis system; it allows sufficient space for discharge analysis of common agricultural nozzles, including wide spray angle nozzles; it contains a motor driven, software controlled X-Y-Z traverse for scanning nozzle spray patterns.

Chemically resistant or inert plastics, metals, and rubber were chosen for most of the chamber components. Structural components were fabricated from Type 304 stainless steel materials. Sheet metal panels were Type 316 to provide enhanced chemical resistance, especially in the sump and base area. Several plastic glazing materials were evaluated in herbicide solutions but none were found to withstand the attack of a wide variety of agricultural formulations while maintaining consistent light transmission characteristics. Therefore, tempered glass, 6-mm thick, cut and drilled to

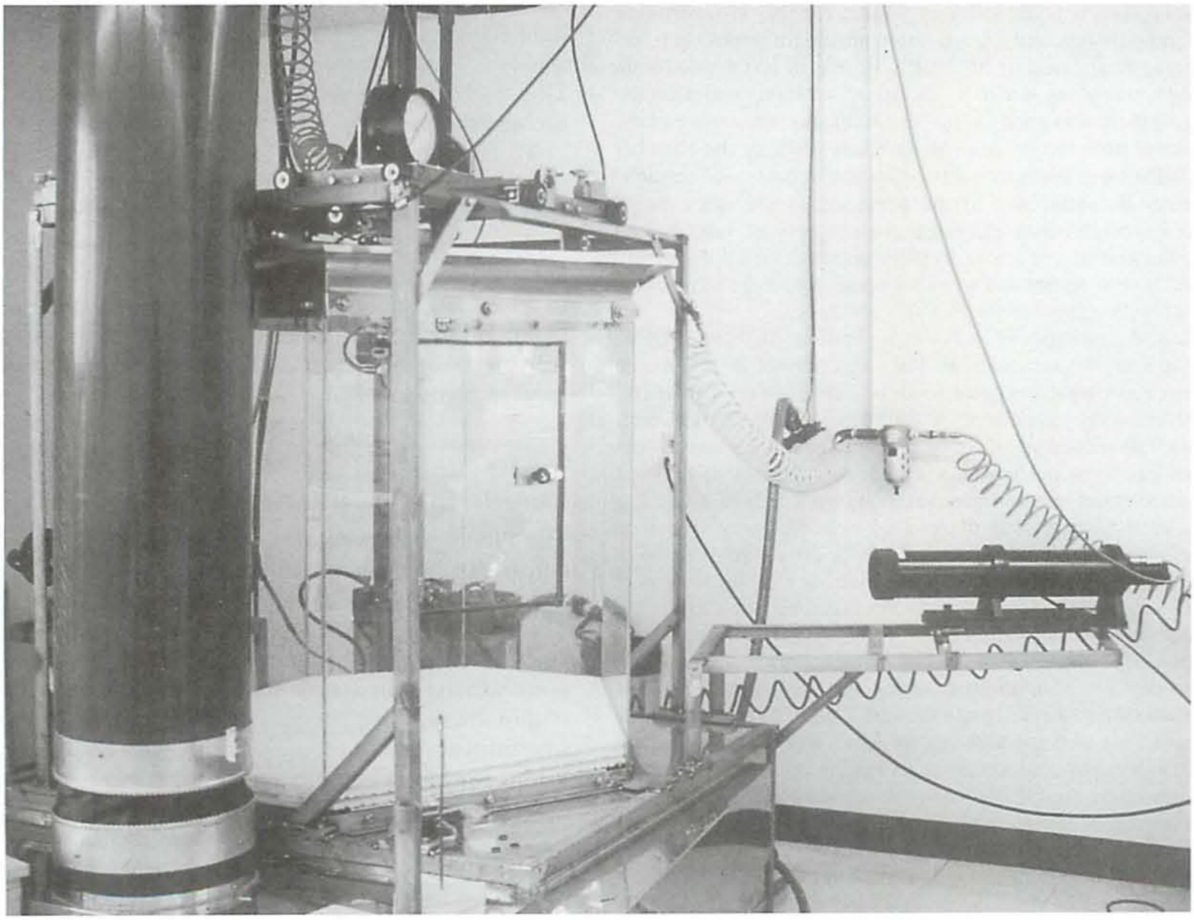

Fig. 1. Installed chamber and PDPA system.

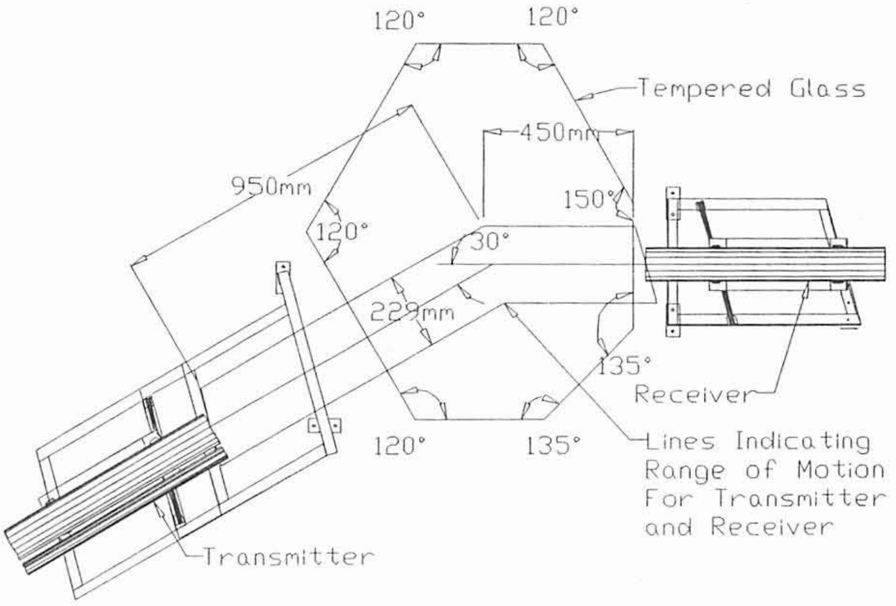

Fig. 2. Spray chamber and PDPA system configuration.

specifications, was used for all glazing. Type 6 molybdenum impregnated nylon was used for the critical transverse bearings as this material combined chemical resistance with excellent wear characteristics. Stainless steel, marine bronze, or nylon fasteners were used with neoprene washers throughout, depending on the application. The vertical or 'Z' transverse was constructed from PVC. All piping, valves, and fittings were brass or nylon (high pressure) or PVC (low pressure) as required.

The geometric configuration of the chamber, as provided by Aerometrics Inc., was a seven sided transparent enclosure, with angles and dimensions as shown in Fig. 2. The maximum chamber radius allowed by the PDPA system was 500 mm, with an effective radius of 450 mm used in the final design. The glazing was designed to be freestanding, requiring only mounts at the bottom and straps at the top corners to maintain rigidity. Six of the glass panels extend 300 mm below the top of the base to maintain laminar airflow past the critical measurement area. The seventh panel terminates at the top of the base to allow access through an easily removed access panel in the base. A 63.5-mm thick flow straightening section constructed from 12-mm square polyethylene grid (similar to the plastic grid used for fluorescent lighting) was located inside the glass enclosure 60 mm above the top of the base to help maintain uniform airflow.

The transmitter and receiver are connected to the chamber base by mounts constructed of 32-mm x 3.2-mm stainless steel angle. Each mount was designed to allow the transmitter or receiver to be moved in such a way that the focal length of the laser remains unchanged. Both mounts incorporate attitude alignment screws and X-Y adjustment slots to allow the chamber operator to focus the laser properly.

Agricultural nozzles designed for 500-mm ground clearance and 110° spray angle can be accommodated by the chamber. One glass panel can be easily removed, allowing the chamber to be extended with a sheet metal section. With these modifications, two nozzles can be used simultaneously to investigate the interaction of overlapping spray patterns. Possible future plans to simulate the effects of forward travel and wind on the spray nozzle discharge pattern will require the removal of two opposing glass panels and the installation of a sheet metal wind tunnel.

The digitally controlled X-Y-Z transverse was mounted on 32-mm x 3.2-mm stainless steel angle (Fig. 3). The 'X' and 'Y' carriages were mounted on 25.4-mm solid square stainless steel with 50-mm diameter wheels machined to fit the square material turned on edge. The stepper motors move the carriages via 22-mm diameter ballscrews, ensuring smooth, accurate motion control. The ballscrews are susceptible to chemical attack and alternative sources for ballscrews of stainless steel and nylon were identified should corrosion problems arise. The 'Z' axis actuator was constructed of two fitted sections of schedule 80 PVC potable water pipe and stainless steel mounts. The pipes were keyed to prevent twisting and improper nozzle location as the actuator is used. Traversing distances are 620 mm longitudinally (X), 260 mm axially (Y), and 600 mm vertically (Z). Three pairs of hermetically sealed microswitches ensure that the traverse system is protected from overextension and provide a reliable reference point for the PDPA system.

Nozzle position is controlled through a traverse controller supplied by Aerometrics Inc. and linked to the computer via a serial interface. Position can be changed manually or by PDPA software control. For software controlled scanning, the user enters the start and end position of the axis to be scanned and the number of locations to be measured. The software then activates movement of the traverse to the start-

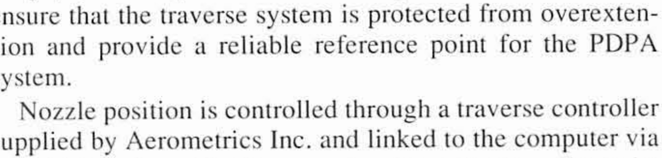

Fig. 3. X - Y axis traverse and Z axis actuator.

ing position, starts data collection, saves the data, and proceeds to the next stop where the process is repeated. When data collection has been completed at the end position, the nozzle is returned to the start position. Traverse speed can be infinitely varied through the traverse controller, with a maximum speed of approximately 20 mm/s. Positioning with this system is very precise and repeatable over a range of scanning methods.

Constructed of 20 gauge Type 316 stainless steel and 32-mm x 3.2-mm Type 304 angle, the base was designed to perform several functions. It provides support for the glazing, transverses, and the PDPA transmitter and receiver, and contains spray effluent and wash-down water for reuse or disposal. The base holds 36 litres, equivalent to 2.4 times the volumes of the spray solution tanks.

Ventilation air can be drawn down through the glazing and the base to ensure removal of all spray particles and vapours. Ventilation air is provided by an Aerovent 380-mm tubeaxial fan (Model 15TF1734, Aerovent Canada Ltd., Mississauga, ON) constructed of fibre reinforced plastic (FRP) for chemical resistance. The fan is powered by a 0.6 kW, 220 V AC single phase electric motor connected to the propeller by variable diameter drive pulleys and a belt. This arrangement allows the operator to adjust airflow to ensure adequate ventilation levels without disturbing nozzle flow patterns. The fan is connected to the chamber by a 300-mm diameter PVC duct through the laboratory ceiling and stainless steel tapered transitions connected to the base. Flow rates up to 1 m^3/min and air velocities up to 2.4 m/s are attainable.

A plumbing diagram of the system is provided in Fig. 4. Spray solution is stored in one or two stainless steel beverage syrup containers of 15 L capacity each, placed on a load-cell equipped stand. The containers are pressurized with filtered and regulated compressed air to maintain consistent spray pressure. The solution is fed to the nozzle through an electrical solenoid valve located near the spray tip. An additional solenoid valve at the solution containers can depressurize the tanks into the chamber sump when testing is completed. This safety feature ensures that the tanks are fully depressurized in a safe containment area before they can be opened. The nozzle effluent can be pumped back into these containers for re-use, or diverted to a large 1000-litre PVC tank for storage and eventual disposal. Spray nozzle pressure is monitored by an analog gauge on the regulator and a Lisle-Metrix stainless steel electronic pressure transducer (Lisle-Metrix, Toronto, ON) located immediately prior to the spray nozzle. A datalogger (Model CR10, Campbell Scientific, Edmonton, AB) monitors the electronic pressure transducer and the load cell to provide (through a serial connection to a separate computer) a record of spray pressure, flow rate, and amount of spray solution left in the tanks.

The wash-down of the chamber is accomplished by a Toftejorg Midget barrel washing nozzle (John Brooks Canada Ltd, Calgary, AB). Wash-down duration is controlled by a time delay relay and an electrical solenoid valve to ensure adequate wash-down while minimizing eventual wash water disposal. Water for wash-down is provided by standard mains water with a minimum of 275 kPa mains pressure.

A simple control panel was furnished with the chamber. Toggle switches for the regulated compressed air solenoid valve and the spray nozzle solenoid valve are interlocked to ensure that the chemical system is pressurized before the nozzle is used. Momentary start and stop switches for the sump pump and wash-down nozzle are connected to time delay relays.

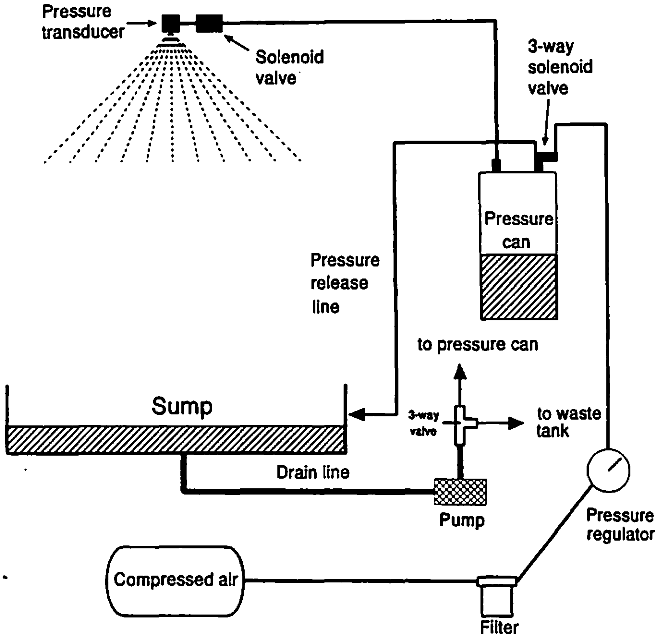

Fig. 4. Spray chamber plumbing schematic.

Operating characteristics

Several experiments were conducted to determine the factors that affect the performance of the PDPA and spray chamber. A single 8001 flat fan nozzle (Spraying Systems Co., Wheaton, IL) spraying tap water was used to evaluate the consistency of the measurement results obtained with the PDPA over a number of days, as well as the effect of the chamber walls and the ventilation fan operation. The operating configuration of the PDPA was kept constant throughout the experimental period to facilitate comparison of results (Table I). The following variables were tested: measurement repeatability using PDPA from day to day; impact of chamber glass enclosure; and impact of downward draft and draft velocity in chamber. The measured parameters were:

Collection runtime The time, in seconds, required for 10,000 droplet measurements to be validated by the PDPA. Longer runtimes are indicative of lower droplet densities passing through the measurement volume or greater incidence of errors causing the rejection of detected droplets by the software.

Sample validation The number of droplets accepted by the PDPA, expressed as a percentage of the number of droplets detected. Lower validation percentages indicate that more detected droplets are rejected by the software.

Mean velocity This identifies the mean velocity of all validated droplets.

Number median diameter (NMD).

Table I: PDPA and chamber configuration

Variable	Selection
Spray solution	Tap water
Nozzle tip	8001 flat fan
Nozzle pressure	200 kPa
Measurement location	450 mm below centre of nozzle
PDPA configuration:	
Collimating lens	160 mm
Transmit lens	1016 mm
Grating track	1 (narrow)
Velocity offset	3.7 m/s
Velocity range	0 - 14 m/s
Diameter measurement range	29.2 - 1021.8 µm
PMT voltage	350 volts
Sample size	10,000 confirmed

Volume median diameter (VMD).

Each measurement was replicated three times and the standard deviation of the three replications was calculated.

RESULTS AND DISCUSSION

PDPA system performance

In the absence of chamber walls, all consecutive measurements of the PDPA system on a given day were found to be very repeatable, with coefficients of variation (CV's) among replicates less than 1% for most parameters. VMD measurements were most variable between replicates, most likely due to the strong impact made on this parameter by relatively few large droplets. Measurements conducted on separate days were also found to be very repeatable, with CV's ranging from 0.9 to 8.6% (Table II). Measured values of the VMD were the most variable over the three days, largely due to fluctuations within days. Fluctuations of the collection runtime among days was 4.8%, but this variation had little effect on droplet size measurements. On the whole, NMD and VMD measurements varied only a few micrometres from day to day. Any differences between days were so small as to be of little practical significance.

Impact of glass enclosure

Enclosing the spray tip output within glass barriers affected several parameters. The runtime increased significantly when the spray was confined in the chamber, but with minimal effect on the sample validation percentage (Table III). This indicates that the detected spray density was lower when the glass was present and can be attributed to a reduction in the laser beam intensity by the glass barrier. As a result, fewer small droplets were detected when the glass was present. The reported mean velocity of the droplets increased somewhat when the glass was present, possibly because a lower number of small, slower moving drops were detected. The reduced detection of small drops by the PDPA due to the glass walls also caused the NMD to rise slightly, as this parameter is very sensitive to the presence of small droplets. VMD, being relatively insensitive to small droplets, was not affected. Increasing the PMT voltage to increase the sensitivity of the PDPA effectively counteracted the effect of the glass (data not shown).

Impact of downward draft

Creation of a downward draft of approximately 0.2 m/s had a small but statistically significant effect on the mean velocity and the NMD of the spray cloud (Table IV). As expected, the mean droplet velocity increased slightly from 3.1 to 3.3 m/s, likely the direct result of droplets moving with the downward draft. The presence of the downdraft decreased the measured NMD slightly. Reductions in the NMD indicate that more small droplets were measured with the downdraft on. It is possible that the vertical air movement of the downdraft reduced the number of small droplets drifting laterally away from the main drift cloud during nozzle operation. With less dispersion of small droplets away from the main cloud, more small droplets would pass through the measurement volume, resulting in a decrease in NMD. There was no effect of the downward draft on VMD.

An increase in the downward vertical air velocity in the

Table II: Repeatability of PDPA measurements as determined by parameters derived from measuring the droplet size spectrum of an 8001 tip operated at 200 kPa, without glass enclosure. Data are presented ± standard deviation of three replicates

Time of measurement	Collection runtime (s)	Sample validation (%)	Mean velocity (m/s)	Number median diameter (µm)	Volume median diameter (µm)
Day 1	67 ± 1.0	96 ± 0.2	2.8 ± 0.02	55 ± 0.2	138 ± 9
Day2	60 ± 1.2	98 ± 0.1	2.8 ± 0.03	58 ± 0.4	138 ± 6
Day3	64 ± 0.4	95 ± 0.3	2.8 ± 0.00	54 ± 0.4	142 ± 21
CV	4.8%	1.3%	0.9	3.0%	8.6%

Table III: The effect of the presence of glass walls separating the spray from the PDPA transmitter and receiver units on PDPA measurements from an 8001 tip operated a 200 kPa. Data are presented ± standard deviation of three replicates.

Glass	Collection runtime (s)	Sample validation (%)	Mean velocity (m/s)	Number median diameter (µm)	Volume median diameter (µm)
No	62 ± 2.2	96 ± 1.6	2.8 ± 0.02	56 ± 2.1	140 ± 14
Yes	88 ± 3.2	98 ± 1.1	3.0 ± 0.07	62 ± 3.2	138 ± 7
LSD (5%)	4.0	2.0	0.08	4.0	16.2

chamber to 0.6 m/s increased the time required to measure 10,000 droplets. This most likely occurred because the sample validation rate was reduced at the high draft velocity (Table IV). It is not clear why sample validation was reduced, especially since validation percentage had not been affected by initiating a downward draft of 0.2 m/s. The mean velocity of the spray remained at 3.3 m/s despite the increased downdraft velocity. The NMD was reduced slightly due to the higher downdraft velocity, likely because a greater number of small droplets passed through the measurement volume due to reduced dispersal of the spray cloud.

Table IV: The effect of the presence of a downward draft in an enclosed chamber on PDPA measurements from an 8001 tip operated at 200 kPa. Data are presented ± standard deviation of three replicates.

Downdraft velocity (m/s)	Collection runtime (s)	Sample validation (%)	Mean velocity (m/s)	Number median diameter (µm)	Volume median diameter (µm)
0.0	85 ± 1.6	99 ± 0.1	3.1 ± 0.02	65 ± 0.3	138 ± 5
0.2	80 ± 1.0	99 ± 0.1	3.3 ± 0.03	63 ± 0.3	137 ± 2
0.6	91 ± 2.3	97 ± 0.3	3.3 ± 0.03	59 ± 0.7	143 ± 5
LSD (5%)	4.4	0.4	0.07	1.1	12.5

CONCLUSIONS

1) The Aerometrics Phase/Doppler Particle Analyzer delivered a consistent performance in measuring the droplet size spectrum emitted by an agricultural nozzle spraying tap water within and among days of operation.

2) The spray chamber constructed to permit 3-dimensional scanning of spray patterns and safe, efficient handling of the spray solution caused only minor changes in the results obtained with the PDPA system:

   a) The glass walls separating the spray cloud from the transmitter and receiver unit caused a reduction in the number of small droplets detected, a situation correctable by increasing the PMT voltage of the receiver unit.

   b) The presence of a fan-induced downdraft in the chamber caused a slight increase in the speed of the droplets, as was expected, and a small decrease in the reported mean diameter of the droplets in the spray, possibly the result of reduced dispersal of small droplets in the presence of a downdraft.

These effects were not considered to be of practical significance.

REFERENCES

Bachalo, W.D. and M.J. Houser. 1984. Phase/doppler spray analyzer for simultaneous measurements of drop size and velocity distributions. *Optical Engineering* 23:583-590.

Johnstone, D.R. 1978. The Influence of physical and meteorological factors on the deposition and drift of spray droplets of controlled size. In *Symposium on Controlled Drop Application*, Monograph #22, 43-57. Croydon, England: British Crop Protection Council.

Lake, J.R. 1977. The effect of drop size and velocity on the performance of agricultural sprays. *Pesticide Science* 8:515-520.

Lefebvre, A.H. 1989. *Atomization and Sprays*. New York, NY: Hemisphere Publishing Corporation.

Merritt, C.R and Taylor, W.A. 1978. Effects of volume rate and drop size on the retention of an aqueous solution by *Avena fatua* L. In *Symposium on Controlled Crop Application*, Monograph #22, 59-65. Croydon, England: British Crop Protection Council.

Spillman, J.J. 1984. Spray impaction, retention, and adhesion: An introduction to basic characteristics. *Pesticide Science* 15:97-106.

Threadgill, E.D. and D.B. Smith. 1975. Effects of physical and meteorological parameters on the drift of controlled-size droplets. *Transactions of the ASAE* 18:51-56.

Wolf, T.M., B.C. Caldwell, G.I. McIntyre and A.I. Hsiao. 1992. Effect of droplet size and herbicide concentration on absorption and translocation of ^{14}C-2,4-D in oriental mustard (*Sisymbrium orientale*). *Weed Science* 40:568-575.