Tarım Makinaları Bilimi Dergisi (Journal of Agricultural Machinery Science)
2017, 13 (2), 121-126

Determining the Droplet Size Classification of Hollow Cone Nozzles with Droplet Image Analysis

Erkan URKAN, Hüseyin GÜLER
Department of Agricultural Machinery and Technologies of Engineering,
Faculty of Agriculture, Ege University-Izmir/TURKEY
Sorumlu yazar: erkan.urkan@ege.edu.tr

Received (Geliş Tarihi): 25.05.2017 Accepted (Kabul Tarihi): 28.07.2017

Abstract: Considering the harmful effects of pesticides, it is necessary to apply them very precisely. The selection of nozzle in pesticide applications is a matter of particular attention. The size of the droplet is very important for fighting with disease and pest. Coarser droplets run-off from the plant while finer droplets are prone to drift. For this reason, it is necessary to determine the droplet diameter in order to reduce drift. Volume median diameter is commonly used for understanding droplet size in the spray pattern.
Due to the direct effect of the size of the droplet, a large number of studies have been conducted on the nozzles. But there are still some missing parts. For this reason, every year the nozzle manufacturers put a new type of nozzle on the market.
In this study, the volume median diameter of different sized (0.8 and 1.0) hollow cone nozzles widely used in Turkey at different pressures (6, 9, 12 bar) in constant temperature and relative humidity were determined by Oxford Visisizer-PDIA (Particle Droplet Image Analysis). It has been determined that the volume median diameter of these two sizes of nozzles, which are tested at lower pressures, is very close to each other.
Key words: Droplet size, Oxford particle analyzer, drift

INTRODUCTION

Spray drift of pesticide is a dangerous issue for the environment. Therefore, it is a direct threat to human health (Damalas and Eleftherohorinos, 2011; Anonymous, 2009). Human-beings, wildlife and the environment are negatively affected by display to spray drift. Also organic farmers are at risk of losing their certification when pesticides drifts on to their field (Immig, 2009). The reduction of this problem is possible but cannot be completely removed. With adjustments on the sprayer, it is possible dramatically to reduce the drift. In this matter, nozzle selection becomes very important issue on this subject.

Droplet size plays an important role depending on the nozzle selection. Understanding the droplet size of the nozzle is an important criterion on decreasing drift. Drift reduction equipment such as nozzles are the easiest way of reducing spray drift at application area. Nozzles on the boom influence the droplet size and correspondingly the potential to drift (Dolarmes, 2009; Harasta, 2009). Understanding the droplet size is important to reduce drift. The smaller the droplet size, means greater the spray drift (Anonymous, 2017d). When operation pressure increases the droplets in the spray pattern becomes finer and the risk of drift tends to increase (Nuyttens et al., 2006).

When applying plant protection products, agricultural nozzles play a vital role in spray pattern. For improving application success operator must pay attention for nozzle selection. Nozzle determines the application rate with pressure, travel speed, and nozzle spacing (Johnson et al. 2000; Grisso et al., 2013; Anonymous, 2002).

The fan nozzles are the most common type of nozzle which is used in a pesticide application technique. These nozzles are used both for the band and broadcast applications. Hollow cone nozzles which are generally used in orchards to apply insecticides or fungicides are also used when penetration and full coverage are important for field crops (Wilson et al., 2008; Johnson and Awetnam, 2000; Grisso et al., 2013).

The nozzle produces a range of droplet sizes in spray pattern that can often be grouped by a single number. This number is called Volume Median Diameter (VMD) (Anonymous, 2017a). VMD is the droplet size in microns at which half the volume released from the nozzle tip will exist as droplets larger than this size and half the volume will exist as droplets smaller than this size (Schick, 1997; Anonymous, 2017a; 2017b; 2017c).

There are different ways to measure the VMD. Using water sensitive papers is the basic method for especially in field experiments, and more sophisticated methods can be used such as real-time spray droplet and particle size measurements. After spraying water sensitive papers are scanned at a high resolution and saved to the computer. After then with the help of image analyzing program the droplets are measured (Guler et al., 2007; Caner, 2007; Urkan, 2012). Another measuring method is optical imaging analyzers. These methods consist of a light or laser source, a video camera and computer system. The light or laser brightens the spray and it is recorded by a video camera. The image on the camera is scanned and the drops are measured with specific formulations (Schick, 1997).

The drift potential of a nozzle is related to the proportion of small droplets in the spray pattern. Droplets, which are smaller than 150–200 μm are easy to move off-target area and in applications, it must be eliminated (Anonymous, 2001). Derksen et al. (1997) and Gordon (2017) suggested that droplets less than 100 μm diameter are highly drift prone droplets and therefore they are difficult to reach to the target.

In particular, optical imaging analyzing measurement method can give more accurate results in laboratory conditions far away from external influences. In this study Oxford Visisizer-PDIA (Particle Droplet Image Analysis) was used to determine the droplet characteristics of hollow cone nozzle which are widely used in Turkey. In the results of the study, important information on the droplet size and hence the performance of the spray parameters for hollow cone nozzles had been shown. This information is useful for operators or farmers who are responsible for using better parameters in field conditions.

MATERIAL and METHODS

In this research, 2 hollow cone nozzles were tested at 3 different spray pressures. The flow rates, number of counting droplets and spraying times are in Table 1. Each nozzle was tested three times and the spray direction was vertically on the measuring system. During the tests water with a temperature of spraying liquid and testing room's temperature was about 22°C and relative humidity was between 60% to 75%. The nozzle was fixed 50 cm height from the measuring line of the Oxford Visisizer-PDIA (Particle Droplet Image Analysis) and mounted on a fully automated system.

Table 1. Nozzle sizes, working pressures, number of counted droplets and spraying time during the experiments

Nozzle Size	Working Pressure(bar)	Flow Rate, ($Lmin^{-1}$)	In-focus Count (No)	Spraying Time (s)
0.8	6	890	10657	231
	9	1080	10887	236
	12	1160	13718	241
1.0	6	1360	11332	421
	9	1680	11727	421
	12	1740	19923	421

All the tests were held in Julius Kühn-Institut, Federal Research Centre for Cultivated Plants Institute for Application Techniques in Plant Protection-Braunschweig-Germany. Measurement system and model was Oxford VisiSizer DP 6401 and software version was VisiSize 6.206. During the experiments the scanning trajectory had a rectangular shape. All tests were carried out through the long axis of the spray pattern with a constant scanning speed of 0.02 m s^{-1}. In the system, there were 3 lens options with different magnification settings. During the measurements the lens option was set to 2 and magnification was set to 1. With this lens and magnification settings the field of view was 9072, the nominal μm/pixel rate was 8.99 and measurement range was from 30 to 2016 μm. This kind of setup was used for measuring spray droplet size measurements and also droplet velocities (Zande et al., 2002; Nuyttens et al., 2009; Guler et al., 2007). Before the experiments were conducted, the water flow rates of each nozzle size were checked at specific working pressures.

A schematic view of the Oxford Visisizer-PDIA laser-based measurement setup is seen in Figure 1. This setup was included a spray system, 2D automated positioning system, digital camera, laser beam, control unit and computer.

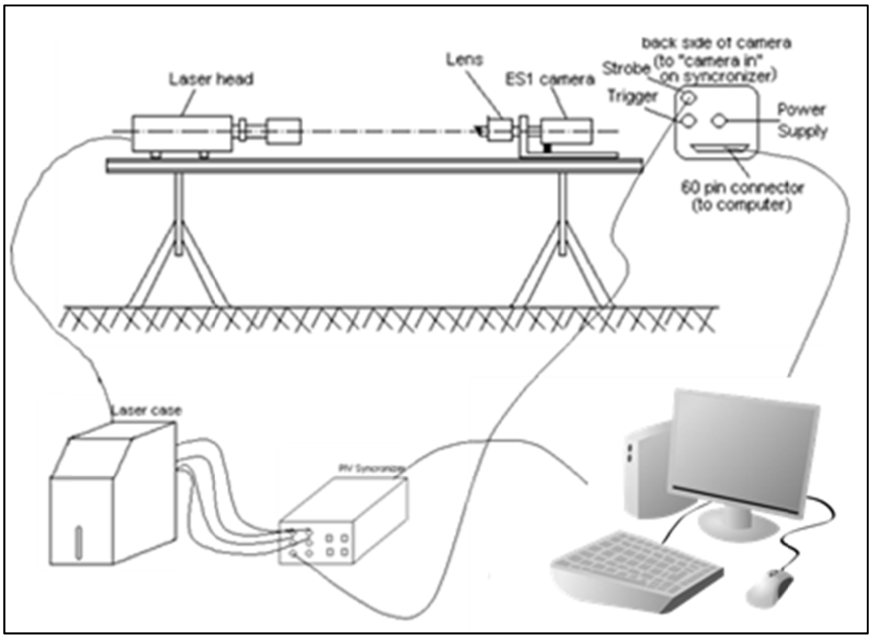

Figure 1. Schematic view of the Oxford Visisizer-PDIA setup (Anonymous, 2017e)

The working principle of the system is explained below according to the producer of the system. A short flash of light illuminates the screen and it brightens the background of the liquid spray. The short pulse freezes the motion of the droplets; this helps the system to capture the droplet size and shape. Captured images are taken via camera and they are sent to a computer and high-speed real-time particle sizing software analyses the droplets (Anonymous, 2017f). With the help of this measurement system spray droplet size measurements in real time with droplet size, velocity and direction can be made. According to Chaker et al. (2002), Matthews (2000), Czacyk et al. (2012) and Petersen (2014) droplet diameter definitions are shown below. These are defined as:

$D_{V0.5}$ is the same as the Volume Median Diameter or Mass Median Diameter (MMD), considering water. This is the representative diameter where 50% of the total volume of the liquid sprayed is made up of droplets with diameters larger than the determined value and 50% is made up of droplets with diameters smaller than the determined value.

$D_{V0.1}$ would symbolizes the diameter of which 10% of droplets are smaller than and $D_{V0.9}$ would symbolize the diameter that 90% of droplets are smaller than.

Relative Span Factor (RSF) is a dimensionless parameter indicative of the uniformity of the droplet size distribution. It is given by:

$$RSF = \frac{D_{V0.9} - D_{V0.1}}{D_{V0.5}}$$

When even distribution of spray is required relative span should be lower. If there is a large difference on droplet sizes cannot be desirable. This leads less even droplet distribution (Anonymous, 2017g, 2017h). $D_{V0.1}$, $D_{V0.5}$, $D_{V0.9}$ and relative span factor of all variables is shown on Table 2. After the experiments, the biggest VMD was found when working with nozzle 1.0 on 6 bars. The smallest VMD was found with nozzle 0.8 when working pressure was 12 bar.

When relative span factor was evaluated the nozzle 1.0 with pressures 6 and 9 bars were found better. Contrarily the rest of combinations vary from 0.84 to 0.89. The volume and coefficient of variation (CV) of the droplets less than 100, 150 and 200 µm during the experiments were shown on Table 3. When the working pressure increased the volume of droplets less than 100, 150 and 200 µm increased.

Approximately 95% and 89% of spray pattern produced from respectively 0.8 and 1.0 size nozzles are less than 200 µm. Considering the spray drift less than 200 µm droplets are highly drift prone. Both nozzles are risky for the application close to sensitive areas such as water sources, people, animals and living areas etc.

Table 2. $D_{V0.1}$, $D_{V0.5}$, $D_{V0.9}$ and relative span factor of nozzles during the experiments

Nozzle Size	Working Pressure (bar)	$D_{V0.1}$ (μm)	$D_{V0.5}$ (μm)	$D_{V0.9}$ (μm)	Relative Span Factor
0.8	6	93	156	230	0.88
	9	88	147	219	0.89
	12	83	143	203	0.84
1.0	6	99	159	269	1.07
	9	90	154	244	1.00
	12	85	145	208	0.85

Table 3. Volume and coefficient of variation of the droplets less than 100, 150 and 200 μm during the experiments

Nozzle Size	Working Pressure, bar	Volume %<100 μm	Volume, %<150 μm	Volume, %<200 μm	CV of 100 μm, %	CV of 150 μm, %	CV of 200 μm, %
0.8	6	13.7	61.4	89.4	1.39	1.16	2.44
	9	17.2	71.3	90.4	4.09	7.42	4.87
	12	19.7	74.0	94.5	5.14	5.73	3.72
1.0	6	10.1	54.7	81.6	0.79	1.85	1.63
	9	12.9	67.4	85.6	0.24	1.30	0.97
	12	13.8	71.2	89.4	0.29	0.99	1.15

The American Society of Agricultural and Biological Engineers ASABE S-572.1 is a standard established by the ASABE that categories the spray from the nozzles into spray size categories fit to the droplet size produced, using a sample reference graph developed from measurements averaged from three laser instruments.

The latest standard ASABE S572.1 was issued March 2009. It is for measuring and understanding spray quality from nozzles were shown on Table 4.

Table 4. ASABE S572.1 Droplet size classification

Spray Quality	Size of Droplets	VMD Range*, (μm)	Color Code
Extremely Fine		<60	Purple
Very Fine		61-105	Red
Fine	from	106-235	Orange
Medium	Small	236-340	Yellow
Coarse	to	341-403	Blue
Very Coarse	Large	404-502	Green
Extremely Coarse		503-665	White
Ultra Coarse		>665	Black

*Estimated from sample reference graph in ASABE/ANSI/ASAE Standard S572.1

Finer sprays provide better deposit on the target such as foliar-acting and contact-acting pesticides. When droplet size is not specified by the label, medium sprays are the most widely used. Coarse sprays are used with systemic, soil-applied herbicides and liquid fertilizer (Anonymous, 2017i). It is known that a systemic pesticide may have better success with a medium, coarse and very coarse droplet while a contact pesticide need fine droplet spectrum for better leaf coverage (Wolf and Brettbauer, 2009). When the result evaluated all VMD results of both nozzles at specific working pressures were in "Fine" spray quality group according to ASABE S572.1.

CONCLUSIONS

Droplet sizing charts are essential for not only the operators but also for the manufacturers. These charts are important also for pesticide manufacturers. The spray quality ratings are used by chemical manufacturers on their labels. These ratings are also used by nozzle manufacturers to rate their nozzles, so that the nozzle operator chooses at a specific rate and pressure, can be matched up with what the chemical label demands.

In this study it is understood that the nozzle which are very close in size have the same spray quality rating. Conversely, when evaluating less than percentage of 100 μm droplets in spray pattern which were produced by 0.8 size nozzle, it is measured that nearly 20% of droplets are less than 100 μm. This value is important to increase spray drift. Although the spray quality is "Fine" for testing both nozzles the 0.8 size nozzle produced more drift prone droplets than 1.0 in 6, 9 and 12 bar working conditions.

ACKNOWLEDGE

These tests were held in Julius Kühn-Institut, Federal Research Centre for Cultivated Plants Institute for Application Techniques in Plant Protection-Braunschweig-Germany. We wish to thank Dr. Andreas Herbst and Mr. Sven Nolte from this Institute for helping during the tests and also Scientific and Technological Research Council of Turkey (TUBITAK) for supporting the research.

REFERENCES

Anonymous, 2001. Selecting the Correct Nozzle to Reduce Spray Drift. Iowa State University. University Extension. IPM 68.

Anonymous, 2002. Spray Drift Management: Principles, Strategies and Supporting Information. Primary Industries Standing Committee. Report 82. 57 pages.

Anonymous, 2009. The Threat of Pesticide Spray Drift. National Toxics Network Inc.

Anonymous, 2017a. http://www.spray-nozzle.co.uk/resources/engineering-resources/droplet-size-measurements

Anonymous, 2017b. https://grdc.com.au/Media-Centre/Ground-Cover-Supplements/Ground-Cover-Issue-122-Spray-application/Spray-speak-droplet-and-drift-terminology

Anonymous, 2017c. http://www.ipmnet.org/tim/pesticide_ed/Pesticide_Courses__2013/Chem_App/Dugan_Peterson Spray_Tips,_Droplet_Size_and_Calibration.pdf

Anonymous, 2017d. B. Wolf, B. Grisso, P. Hpikins, T. Reed http://offices.ext.vt.edu/carroll/programs/anr/cc_pesticide_training_files/droplets_v6.pdf

Anonymous, 2017e. A Brief Manual for Oxford Laser Imaging System and Visisize Software

Anonymous, 2017f. https://www.oxfordlasers.com/imaging/particle-size-measurement/

Anonymous, 2017g. http://www.spray-nozzle.co.uk/resources/engineering-resources/droplet-size-measurements

Anonymous, 2017h. http://www.bete-nozzles.com/services/nozzle-basics/droplet-size.html

Anonymous, 2017i. http://cdn2.hubspot.net/hub/95784/file-32015844-pdf/docs/asabe_s572.1_droplet_size_classification.pdf

ASABE S572.1, Standard of Droplet Size Classification. The American Society of Agricultural and Biological Engineers (ASABE).

Caner, Ö. K., (2007). Yardımcı Hava Akımlı Hidrolik Pülverizatörle Bağ İlaçlamasında Toprak Yüzeyine Sürüklenmeyi Azaltmaya Yönelik En Uygun Kullanım Koşullarının Belirlenmesi, (Doktora Tezi), Ege Üniversitesi Fen Bilimleri Enstitüsü Tarım Makinaları Anabilim Dalı, Bornova-İzmir (Yayınlanmamış).

Chaker M., C. B. Meher-Homji, T. Mee, 2002. Inlet Fogging of Gas Turbine Engines - Part B: Fog Droplet Sizing Analysis, Nozzle Types, Measurement and Testing. Proceedings of ASME Turbo Expo 2002 June 3-6, 2002 Amsterdam, The Netherlands

Czacyk Z., G. Kruger, A. Hewitt, 2012. Droplet Size Classification of Air Induction Flat Fan Nozzles. Journal of Plant Protection Research Vol. 52, No. 4 (2012) DOI: 10.2478/v10045-012-0068-6

Damalas C. A. and I. G. Eleftherohorinos, 2011. Pesticide Exposure, Safety Issues, and Risk Assessment Indicators. Int. J Environ Res Public Health. 2011 May; 8(5): 1402–1419. doi: 10.3390/ijerph8051402

Delormes P., 2009. Habitat Protection from Pesticide Spray Drift: The Canadian Approach. Report of the Seminar on Pesticide Risk Reduction through Spray Drift Reduction Strategies as Part of National Risk Management. OECD Environment, Health and Safety Publications Series on Pesticides No. 46. Pp. 26-33.

Derksen, R. C., H. E. Ozkan, R. D. Fox and R. D. Brazee, 1997. Effectiveness of TurboDrop and Turbo TeeJet nozzles in drift reduction. ASAE Paper No. 971070, ASAE, 2950 Niles Road, St. Joseph, MI 49085.

Grisso, R., P. Hipkins, S. D. Askew, L. Hipkins, D. Mccall, 2013. Nozzles: Selection and Sizing. College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University. Publication 442-032. https://pubs.ext.vt.edu/442/442-032/442-032_pdf.pdf

Gordon B., 2017. Spray Application Manual for Grain Growers. Grain Research and Development Corporation Grow Notes, pp 22.

Guler, H., H. Zhu, H. E. Ozkan, R. C. Derksen, Y. Yu, and C. R. Krause. 2007. Spray characteristics and drift reduction potential with air induction and conventional flat-fan nozzles. Trans. ASABE 50(3): 745-754.

Harasta P., 2009. Drift Reduction Possibilities in the Czech Republic. Report of the Seminar on Pesticide Risk Reduction through Spray Drift Reduction Strategies as Part of National Risk Management. OECD Environment, Health and Safety Publications Series on Pesticides No. 46. Pp. 43-48.

Immig J., 2009. The Threat of Pesticide Spray Drift. A Community Information and Action Kit

Johnson M. P. and L. D. Swetnam, 2000. Sprayer Nozzles: Selection and Calibration. University of Kentucky Cooperative Extension Service. PAT-3.

Matthews G.A, 2000. Pesticide Application Methods. Blackwell Sciences. ISBN 0-632-05473-5. p. 431

Nuyttens D., M. De Schampheleire, P. Verboven, E. Brusselman, D. Dekeyser, 2009. Droplet Size and Velocity Characteristics of Agricultural Sprays. Transactions of the ASABE Vol. 52(5): 1471-1480, American Society of Agricultural and Biological Engineers ISSN 0001-2351. Pp. 1471-1480.

Nuyttens D., Baetens K., Schampheleire M. De, Sonck B., 2006. PDPA Laser Based Characterization of Agricultural Sprays. Agricultural Engineering International: the CIGR Ejournal. Manuscript PM 06 024. Vol. VIII. December, 2006.

Petersen D., 2014. WA Weed Conference – Crop Session. Pp. 4

Schick R. J., 1997. General Guidelines on Drop Size Measurement Techniques and Terminology. As presented at the 47th Chemical Processing Industry Exposition, Javits Convention Center, New York, November 1997.

Urkan, E., (2012). Farklı Tip Memelerle Bağ İlaçlamasında Pülverizatör Performansının ve Sürüklenmenin Belirlenmesi, (Doktora Tezi), Ege Üniversitesi Fen Bilimleri Enstitüsü Tarım Makinaları Anabilim Dalı, Bornova-İzmir (Yayınlanmamış).

Wilson J., J. Nowatzki, V. Hofman, 2008. Selecting Drift-Reducing Nozzles. South Dakota Cooperative Extension Service. FS 919 Rev. 6/08

Wolf R.E. and S. Brettbauer, 2009. Droplet Size Calibration: A New Approach to Effective Spraying. Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

Zande, J. van de, H. A. J. Porskamp, H. J. Holterman, 2002. Influence of Reference Nozzle Choice on Spray Drift Classification. Aspects Appl. Biol., Intl. Adv. Pest. Appl. 66: 49-55.