Droplets velocity estimated by impact forces[1]

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Abstract

The velocity of the sprayed droplets indicates the force those droplets impact with the target surface and can indicate its trajectory (penetration form) in the interior of the canopy. In order to estimate the droplets velocity two methods were developed - the droplets impact force over a surface and the liquid flow rate measurement. To measure the impact forces it was used an impact plate with high sensitivity hardwired to a microcomputer equipped with software capable to register forces with low intensity. At the same time it was developed a system of liquid collection with the same area of collection of the impact plate and used a precision scale to quantify the liquid that passes in that section. Afterwards, the velocity of the droplets sprayed by different nozzles was estimated. The results show that it is possible to collect the droplets impact forces using an impact plate with high sensitivity and also to measure the liquid flow rate that passes to the same section of the impact plate. It is possible to estimate the velocity of the droplets sprayed by different nozzles using the impact forces and the liquid flow rate that goes through the same area of the plate.

Key words: impact forces; liquid flow rate; droplet velocity.

Introduction

There are several ways to represent the spectrum of droplets generated by a spray. Matthews (2000) mentions that the spectrum of a spray droplets is usually studied by its volume median diameter (VMD), diameter median number (DMN), coefficient of dispersion (r) and relative magnitude. The mechanisms of breaking the layer of liquid were studied by Butler-Ellis and Tuck (1999) for five types of conventional nozzles and seven different liquids. The authors argue that the common way to break the liquid for the standard solutions is perforation and for the emulsions is oscillation and when increasing the length of the liquid shear it results in smaller droplets.

Among the characteristics that influence the trajectory of the droplets towards the target, Matuo (1990) mentions temperature, relative humidity, wind speed and barometric pressure. In tropical conditions of high temperature the phenomenon of evaporation of droplets is highly problematic and increases in extremely dry days with low relative humidity.

Farooq et al. (2001) argue that the droplets of the discharge of a nozzle slow down when scrolling vertically and when there is lateral wind action they also have horizontal deceleration. The authors argue that the deceleration of the droplets is essentially determined by the reduction of the inertia, basically determined by their weight instead of its initial energy. Near the end of the nozzle the smaller droplets move more slowly than the bigger ones and further from the nozzle the velocity of small droplets may have negative velocity, indicating that they are moving upwards.

Bergeron et al. (1999) divided the phenomenon of the impact of droplets in three stages: impact, expansion and retraction. The impact and expansion occurring within 2 milliseconds after the impact and the physical phenomena that occur is controlled by the forces of inertia, viscosity and capillarity. In the stage of the retraction, which occurs during the subsequent 10-50 milliseconds the droplets can rebound from the surface or simply slowly retract to its balance position. These events are controlled by the competition between the forces of viscous dissipation of droplets and the forces of capillarity that try to minimize the surface area of droplets. After the retraction the long-time events are controlled by the classical laws of thermodynamics, such as the coefficient of dispersion and the angle of contact.

According to Miller and Butler-Ellis, (2000) it is common to relate the drift from a given nozzle by the percentage of spray volume of droplets smaller than 100 mm in diameter. Those authors suggest that there is a need to measure the physical parameters of the spectrum of the droplets including the distribution of size and velocity, the structure of the spectrum of droplets and the wind speed inside the spray, to better understand the behavior of droplets.

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Southcombe et al. (1997) mention that the presence of air bubbles inside the droplets influences transport and deposition. Combellack and MILLER (2001) go further and say that the presence of air within the droplets influences size, velocity, form of impact, retention and drift of those droplets.

According to Miller (2001), the velocity of droplets at the output of a spray of air induction nozzles is generally lower than the velocity of droplets generated by conventional nozzles, and because of high strength retention in relation to the mass, they usually have lower velocity when they impact with the surface.

Using imaging probe Particle Measuring Systems (PMS), Butler-Ellis and Tuck (2000) report that the droplets with air into their interior have lower velocity than the droplets produced by conventional nozzles and that can be affected by the type of liquid used. Few studies are pursued to the velocity of droplets, especially given the high cost of laser equipment used to examine the measurements.

The purpose of this study was to develop two methods in order to measure the impact forces and the liquid flow rate of droplets sprayed by different nozzles, as well as estimate their velocity.

Materials and methods

The activities described in this study were conducted in the laboratories of the Silsoe Research Institute in England. The air induction nozzles were produced by Billericay Farm Services, Billericay, Essex, England (Model A), Hardi International, Taastrup, Denmark (B); Spraying Systems, Wheaton, Illinois, USA (C); Sprays International, Paul Street, London, England (D). The conventional spray nozzles type XR were produced by Spraying Systems (E).

A series of four nozzles from different flow rates were used in each model of nozzles. The four series of flat fan nozzles with air induction (from A to D) were identified by AI (air induction) and a series of conventional nozzles (E) was identified by the acronym PC (conventional nozzle) without air induction. The flow rate of the series of nozzles of each model was: 015, 02, 03 and 04 (U.S. gallons per minute). In addition, four 02 and four 04 air induction nozzles models C and D were used. All types of nozzles were manufactured to generate a 110° angle of application.

The solution used to conduct the tests was prepared with 0.1% of non-ionic surfactant agral and water in volume made an aqueous solution not concentrated. According to Montorio (2001) the agral surfactant causes the lowering of the water surface tension, reaching the minimum level even before the concentration reaches 0.1% and by increasing the concentration, the surface tension of the liquid remains stable. That spray solution is widely used in Silsoe Research Institute (SRI) laboratories to conduct routine assessments of spray nozzles. In addition, Gilbert (2000) also indicates the use of non-ionic surfactant to test the performance of nozzles.

Five working pressures were applied to the fluid (200, 250, 300, 350 and 400 kPa) in all treatments. To control the pressure it was used a sensor in the tube near to a nozzle connected to a digital display where the reading was done. The working pressure was adjusted by varying the entry of air into the canister with the spray solution using a pressure regulating valve.

The experiment included the measurement of droplets impact forces in the central longitudinal section of the spray and the determination of the liquid flow rate that goes through the same section where the spray impact forces were measured.

The experimental design used was sub divided box plots. Treatments were organized in the schedule 5 x 4 x 5 (5 different types of nozzles x 4 flow rate x 5 pressures), with 3 replications. An additional set of tests was conducted to the C and D model of nozzles and considered the schedule of 2 x 5 x 5 (2 flow rate x 5 pressures x 5 nozzles of each model), to examine the variability of results within the sample of nozzles. The nozzles flow rate used were 02 and 04.

In order to collect data to determine the forces remaining on the impact plate, another test was done with additional nozzles of the model C according to schedule 2 x 2 (2 flow rate x 2 pressures), with 3 replications. Nozzles 02 and 04 at pressures of 200 and 400 kPa were used.

The velocity of the droplets in a particular area of the spray was estimated with the averages impact forces of the droplets and the liquid flow rate. The overall results obtained in the experiment were subjected to analysis of variance using the SAS®, and when the F test was significant the averages were compared using the Tukey test at 5% level of probability. The standard deviation of droplets impact forces and the liquid flow rate was also calculated.

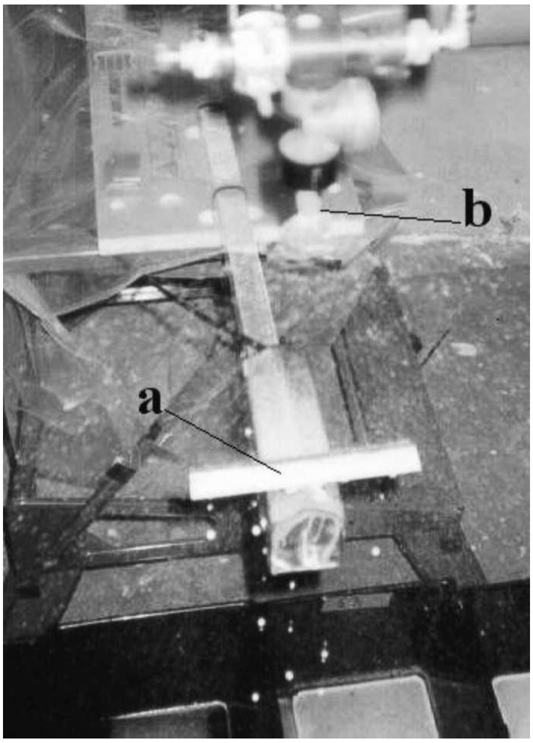
To measure the forces generated by the impact of the spray droplets on a surface it was used an impact plate measuring 25 by 150 mm adjourned for a load cell with a sensitivity of 0,005 Newton (Figure 1), based on the description of MURPHY (2000). The load cell was connected to a computer to record the droplets impact forces of the spray section which reached the solid surface of the plate.

The impact forces were recorded on the computer in text format, using the software Sprayforce V2.01 (Paul Twydell, 1999, Silsoe Research Institute). The software was programmed to record 10 readings per second. The time of collection of each sample was 20 seconds. Subsequently, the data were transferred to Microsoft Excel® to be organized and analyzed. During data gathering the impact plate was positioned 200 mm below each exit nozzle hole in the center of the spray parallel to its longest axis. The adjustment of working pressure in each sample was made before starting the collection of data and the adjustment of spraying pressure was carried out for a few seconds by using the digital display as reference.

During the spraying a quantity of liquid remained over the board of the impact plate generating an error reading. The forces generated by that liquid were measured using a 02 and 04 nozzle of model C both at pressures of 200 and 400 kPa. The same procedure was adopted to collect the final samples, but 10 seconds after the start of spraying the flow of droplets was stopped and the record of impact forces was maintained on the computer until completing 20 seconds. The average of forces recorded in the last 10 seconds was subtracted from each record of forces in all treatments.

In order to collect the liquid flow rate contained in the droplets that hit the impact plate in the time of collection a liquid flow collector (Figure 2) was built with the same area of collection as the

Figure 1. Impact plate (a) with a nozzle spraying (b).



impact plate. A container was placed at the bottom of the collector to receive and store the liquid that passed thought the collection area.

The collector was placed in the same position as of the impact plate that is, at the center of the spray, parallel with its longest axis, 200 mm below the nozzle of each spray. Before starting the spraying, a plate was placed at the top of the collector to close the entrance. To start spraying the liquid output register was opened and then the plate that was over the collector was removed. After 60 seconds of collection the plate was replaced and the output register closed. Then the container with the liquid was weighed in order to determine the mass of liquid. The liquid flow rate was found by dividing the mass of liquid by the time of collection (Equation 1).

$$F = \frac{M}{T} \qquad (1)$$

Where,
Fl = Liquid flow, kg.s^{-1}
Ml = Liquid mass, kg
T = Time of collection, s

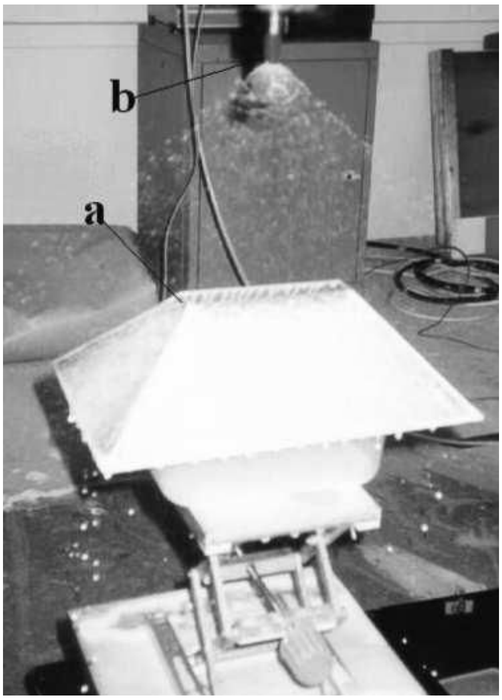
It was possible to find the velocity of the droplets by dividing the impact force of droplets on a known surface area by the mass flow of the liquid that passes in the same area. It was assumed that the mass of liquid that passed through the collection area of the liquid flow collector is equivalent to that which reached the plate of impact in each sample because they have equivalent areas and because the collections have been made in the same period of time.

Initially the data units were adjusted in order to be able to divide the impact forces by the liquid flow, obtaining as a result the droplets velocity at 200 mm from the edge, given in ms^{-1} (Equation 2).

$$Vg = \frac{F}{Fl} \qquad (2)$$

Where,
Vg = Droplets velocity, m.s^{-1}
F = Droplets impact forces, N
Fl = Liquid flow, kg.s^{-1}

Figure 2. Liquid flow collector (a) with a nozzle in operation (b).



Results and discussion

Table 1 shows a summary of the nomenclature used to describe the treatments and the factors evaluated.

Droplets impact forces

The impact forces of the droplets generated by 02 nozzles working from 200 to 400 kPa of pressure (Figure 3) are lower than the 04 nozzles (Figure 4). The air induction nozzles have shown greater variability than those generated by conventional equivalent nozzles in all pressures studied.

The impact forces of droplets generated by 04 nozzles were higher than those generated by equivalent 02 nozzles. This may be because of the increased flow of 04 nozzles in relation to the 02 nozzles.

The impact forces of droplets generated by air induction nozzles have greater variability than that generated by conventional nozzles working under the same conditions. Thus, the nozzles with air induction generated larger droplets and fewer in number then the equivalent conventional nozzles with the same flow rate.

Liquid flow rate

Figure 5 shows the average liquid flow rate of three repetitions using the nozzles of the series C with air induction and conventional series E and with 02 and 04 flow rate. As expected the results show that the liquid flow rate increases by increasing working pressure as well as the use of spray nozzles with higher flow rates. The average liquid flow of the air induction nozzles was higher than the conventional equivalent, especially for the 02 nozzles.

Droplets velocity

Figure 6 shows that the droplets generated by 04 conventional nozzles have higher velocity than the droplets generated by air induction nozzles. It occurs also for the 02 nozzles in all pressures studied.

The velocity of the droplets is lower for air induction nozzles then for the conventional ones in agreement with Butler-Ellis et al. (2001) who found similar results using a solution with surfactant. Furthermore those authors using conventional spray nozzles found that the velocity of the droplets was the same in solutions containing surfactant or just water.

According to FAGGION (2002) increasing the percentage of air induced by most of the 02 and 04 nozzles working at 300 kPa of pressure decrease its velocity. Those results were expected because the presence of air within the droplets increases its diameter and decreases its density.

The highest velocity of the droplets with higher density leads one to believe that those droplets suffer lower drift than those of conventional nozzles. However, the droplets with lower density due to the

Table 1. Treatments and description of the factors evaluated

Treatements	Factors avaliated
Model A	IA - air induction - Billericay Farm Services
Model B	IA - air induction - Hardi International
Model C	IA - air induction - Spraying Systems
Model D	IA - air induction - Sprays International
Model E	XR - conventional - Spraying Systems
Flow rate 015	110015
Flow rate 02	11002
Flow rate 03	11003
Flow rate 04	11004
Pressure 200	200 kPa
Pressure 250	250 kPa
Pressure 300	300 kPa
Pressure 350	350 kPa
Pressure 400	400 kPa

Figure 3. Droplets impact forces generated by 02 nozzles working at different pressures. The vertical bars indicate the standard deviation.

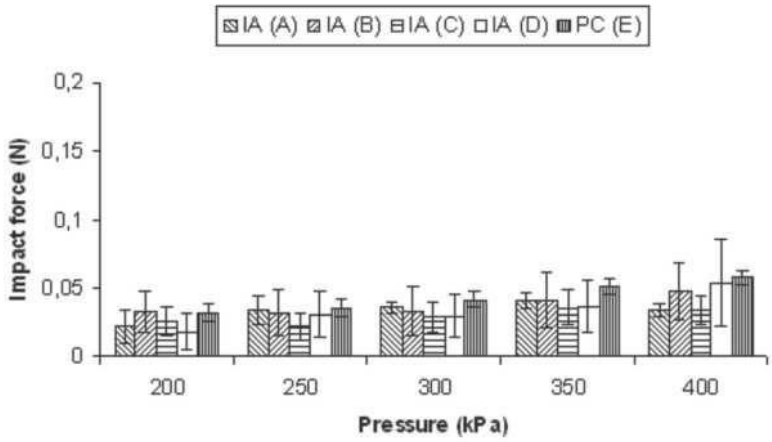


Figure 4. Droplets impact forces generated by 04 nozzles working at different pressures. The vertical bars indicate the standard deviation.

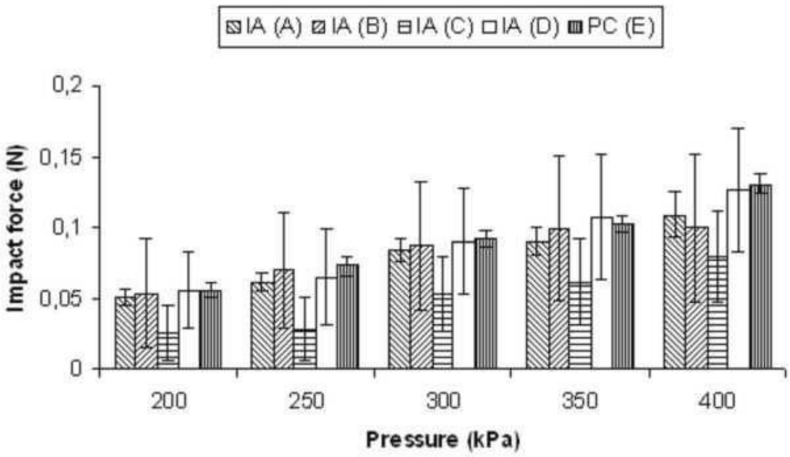


Figure 5. Liquid flow rate of two 02 (empty) and two 04 (full) nozzles where one with air induction and another conventional, working from 200 to 400 kPa of pressure.

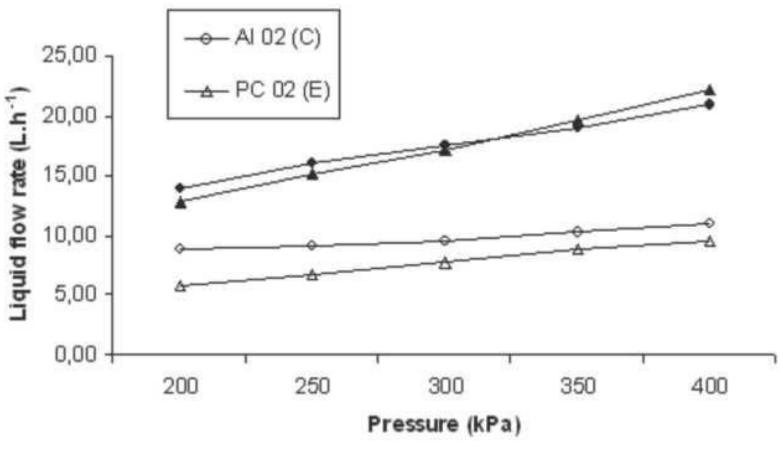
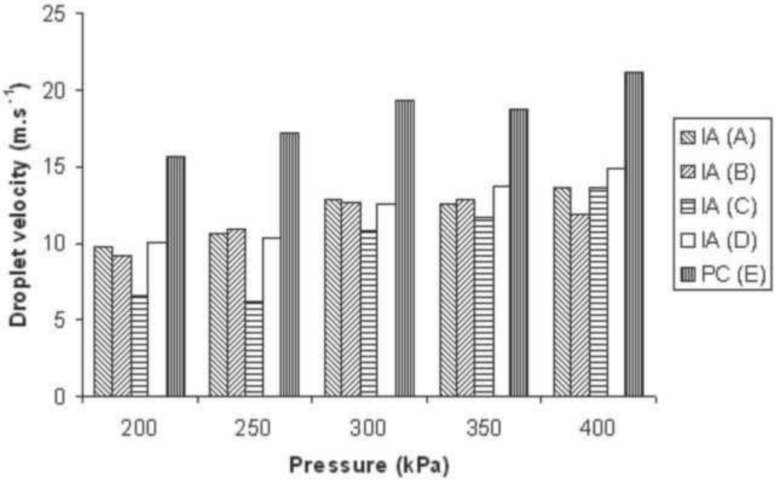


Figure 6. Droplets velocity generated by 04 nozzles working at different pressures.



presence of air in their interior normally suffer lower drift when studied at wind tunnel, probably because they have bigger size and bigger mass.

In this work the average velocity of droplets 200 mm below the 015 conventional nozzles working at 300 kPa of pressure was 23.76 ms-1. Miller (1993) found droplets velocity about 20 ms-1 using the Aerometrics spray analyzer and water with 0.1% of a non-ionic surfactant on a nozzle with the same characteristics working under the same pressure. Through a graphical representation that author shows that DOMBROWSKI and JONES (1963) found that the velocity of the blade nozzle between 15 a 25 m.s-1.

The extent of impact forces shows greater variability of impact forces of the droplets generated by air induction nozzles in relation to conventional equivalents. The greater range of forces indicates that the air induction nozzles generated fewer droplets with different mass. Some of those droplets have larger mass than the largest droplets generated by conventional equivalent nozzles.

Conclusions

It is possible to measure the droplets impact forces using an impact plate with high sensitivity and store the forces on a computer. This method detects greater range of impact forces of droplets generated by air induction nozzles than the conventional nozzles.

It is possible to measure the liquid that impacts with the impact plate by collecting the droplets sprayed during the same time using a collector with the same area of the collection as that of the impact plate.

Considering the impact forces of droplets and the liquid flow rate that goes through the same area of the impact plate it is possible to estimate the velocity of droplets in a certain position of the spray.

References

BERGERON, V. MARTIN, J. Y. VOVELLE, L. Interaction of droplets with a surface: impact and adhesion. Agro Food Industry Hi-Tech, 10: 5, p.21-23, 1999.

BUTLER-ELLIS, M. C., BRADLEY, A. e TUCK, C. R. The characteristics of sprays produced by air induction nozzles. In: THE BRITISH CROP PROTECTION COUNCIL CONFERENCE – WEEDS, 2001, Brighton. Proceedings… Surrey: The British Crop Protection Council, 2001, p.665-70.

BUTLER-ELLIS, M. C., e TUCK, C. R. The variation in characteristics of air-included sprays with adjuvants. Aspects of Applied Biology, v.57, p.155-162, 2000.

BUTLER-ELLIS, M.C., TUCK, C.R. How adjuvants influence spray formation with different hydraulic nozzles. Crop Protection, v.18, p.101-109, 1999.

BUTLER-ELLIS, M.C., TUCK, C.R. e MILLER, P.C.H. How surface tension of surfactant solutions influences the characteristics of sprays produced by hydraulic nozzles used for pesticide application. Colloids and Surfaces. Physicochemical and Engineering Aspects, v.180, p.267-76, 2001.

COMBELLACK, J. H. e MILLER, P. C. H. Effect of adjuvants on spray patternation and the volume of air induced by selected nozzles. In: THE 6TH INTERNATIONAL SYMPOSIUM OF ADJUVANTS FOR AGROCHEMICALS, 6, Amsterdam. Proceedings… 13-17 August 2001, p.557-62.

DOMBROWSKI, N e JONES, W. R. The aerodynamic instability of viscous liquid sheets. Chemical Engineering Science. 18, p.203-14, 1963.

FAGGION, F. Desenvolvimento de Métodos para Estimar a Quantidade de Ar Incluído às Gotas por Pontas de Pulverização com Indução de Ar. Botucatu, 2002. 73p. Tese (Doutorado em Agronomia/Energia na Agricultura) – Faculdade de Ciências Agronômicas, Universidade Estadual Paulista.

FAROOQ, M., BALACHANDAR, R., WULFSOHN, D. e WOLF, T. M. Agricultural Sprays in Cross-flow and Drift. Journal of Agricultural Engineering Research, vol. 78, n. 4, 2001. p.347-58.

GILBERT, A. J. Local Environmental Risk Assessment for Pesticides (LERAP) in the UK. Aspects of Applied Biology, v.57, p.301-307, 2000.

MATTHEWS, G. A. Pesticide application methods. 3.ed. London: Blackwell Science Ltd, 2000. 432p.

MATUO, T. Técnicas de aplicação de defensivos agrícolas. Jaboticabal: Funep, 1990. 139p.

MILLER, P. C. H. Directions and trends in research into pesticide application technology – The view of a research scientist. In: II SIMPÓSIO INTERNACIONAL DE TECNOLOGIA DE APLICAÇÃO DE AGROTÓXICOS: EFICIÊNCIA, ECONOMIA E PRESERVAÇÃO DA SAÚDE HUMANA E DO AMBIENTE. Jundiaí. 2001. Disponível em <http://www.iac.br/~cma/Sintag>.

MILLER, P. C. H. e BUTLER-ELLIS, M. C. Effects of formulation on spray nozzle performance for application from ground-based boom sprayers. Crop Protection, v.19, p.609-15, 2000.

MILLER. P. C. H. Spray drift and its measurement. In: MATTHEWS, G.A., HISLOP, E.C. (Ed.). Application technology for crop protection. Wallingford: CAB International, 1993. p.101-22.

MONTÓRIO, G. A. Eficiência dos surfactantes de uso agrícola na redução da tensão superficial. Botucatu, 2001. 70p. Tese (Doutorado em Agronomia/Energia na Agricultura) – Faculdade de Ciências Agronômicas, Universidade Estadual Paulista.

MURPHY, S. D. The study of droplet impact force and spray deposition from BCPC reference nozzles and air-inclusion nozzles for the classification of agricultural spray nozzles. Relatório final apresentado ao Silsoe Research Institute, 2000.

SOUTHCOMBE, E. S. E., MILLER, P. C. H., GANZELMEIER, H., VAN DE ZANDE, J. C., MIRALES, A. e HEWITT, A. J. The international (BCPC) spray classification system including a drift potential factor. In: THE 1997 BRIGHTON CROP PROTECTION CONFERENCE - WEEDS, 1997, Brighton. Proceedings… Surrey: British Crop Protection Council, 1997, p.371-80.