AUTOMATED BOOM SPRAYER PROTOTYPE

ALVES, Fernando Lima[1]
MAGGI, Marcio Furlan[2]
MOREIRA, Wendel Kaian Oliveira [3]
OLIVEIRA, Daiane de Deus[4]
BENEDUZZI, Humberto Martins[5]

Recebido em: 2021.07.04 **Aprovado em:** 2022.03.08 **ISSUE DOI:** 10.3738/1982.2278.3997

SUMMARY: Pesticide application has contributed to increase the crop yield worldwide. Electronic control units, sensors, actuators, onboard computers, geographic information systems and satellite remote sensing have been employed in modern agricultural machines to safely, quickly, and accurately monitor and control machine operation and record data for real-time or offline analysis. The aim of this study was to develop an automated boom sprayer prototype with section control for pesticide application, thereby obviating the need for manual operator intervention and reducing the risks of contamination. A complete prototype was developed containing three independent application circuits. Spray quality was assessed using water-sensitive paper and a working pressure of 59.46 bar. The following parameters were determined: volumetric median diameter, numeric median diameter, droplet density, coverage percentage, and droplet volume. The flow rate of each nozzle was in accordance with manufacturer specifications. The prototype was robust and effective in quickly alternating between boom sections without manual intervention of the operator.

Keywords: Pesticide application. Technological innovation. Spray nozzle. Section control.

PROTÓTIPO DE AUTOMAÇÃO PARA PULVERIZADORES DE BARRA

RESUMO: A aplicação de pesticidas tem contribuído para o crescimento da produtividade agrícola do País, por conseguinte, controladores eletrônicos têm sido utilizados na agricultura moderna. A eletrônica embarcada na agricultura é representada pelo uso de sensores, atuadores, computadores de bordo, softwares e sistemas de informações geográficas via satélite instalados nas máquinas agrícolas. Seu objetivo é monitorar a operação das máquinas, realizar algum tipo de controle automático e registrar dados para análise posterior ou em tempo real. Os sistemas de automação permitem monitorar e controlar o funcionamento de um sistema físico de forma segura, rápida e precisa. O objetivo deste trabalho foi o desenvolvimento de um protótipo de automação para a transição de bicos de pulverizadores com um dispositivo eletrônico embarcado, diminuindo os riscos de contaminação ao operador por não haver contato manual na substituição. Foi desenvolvido um protótipo completo contendo 3 circuitos de aplicação controlados de forma independente para cada tipo de conjuntos de pontas. As aplicações foram realizadas sobre papel hidrossensível, cujos bicos na pressão de trabalho estavam calibrados em 59.46 bar, em que foi avaliado a qualidade de aplicação com o levantamento dos seguintes parâmetros: diâmetro mediano volumétrico – DMV, diâmetro mediano numérico – DMN, densidade de gotas, % de cobertura e volume das gotas. Os resultados dos testes de vazão ficaram de acordo com os dados do catálogo fornecido pelo fabricante das ponteiras testadas. O protótipo apresentou-se robusto e eficiente para a utilização prática, sendo possível realizar a troca das ponteiras de forma rápida e sem contado manual do operador.

Palavra-chave: Automação, Aplicação de Agrotóxicos, tecnologia embarcada.

INTRODUCTION

[1] ORCID ID - https://orcid.org/0000-0001-7928-180X Instituto Federal do Paraná (IFPR), Cascavel – PR, Brasil
[2] ORCID ID - https://orcid.org/0000-0003-0353-1846 Programa de Pós-graduação em Engenharia agrícola, Universidade Estadual do Oeste do Paraná, Campus Cascavel, Paraná.
[3] ORCID ID - https://orcid.org/0000-0002-7778-0151 Programa de Pós-graduação em Engenharia agrícola, Universidade Estadual do Oeste do Paraná, Campus Cascavel, Paraná.
[4] ORCID ID - https://orcid.org/0000-0002-0388-3940 Programa de Pós-graduação em Engenharia agrícola, Universidade Estadual do Oeste do Paraná, Campus Cascavel, Paraná.
[5] ORCID ID - https://orcid.org/0000-0002-9004-8678 Instituto Federal do Paraná (IFPR), Foz do Iguaçu – PR, Brasil.

Agricultural spraying finds a variety of applications in the management of modern crops. It allows controlling weeds (MOHAMED *et al*., 2018), protecting plants from pests and diseases (KAUR *et al*., 2019), and applying nutrients and fertilizers. The environmental and productivity advantages of no-till farming depend on the correct use of this agricultural technique. For an effective pesticide application, it is necessary to take into account some important factors, including type of crop, pest, and product; sprayer type and calibration; and climatic conditions. The appropriate climatic conditions for spraying are those that result in low evaporation rate and drift losses, and allow plants to absorb and translocate the material: average temperature of 10°C; average relative humidity of 81% (BALSARI *et al*., 2017), and wind speed of 3 and 7 km h^{-1} (BAIO *et al*., 2019). In periods of intense rainfall or drought, optimum spraying conditions may occur only for a few hours or not at all, contributing to the development of pathogens (GRAMMATIKIS *et al*., 2020).

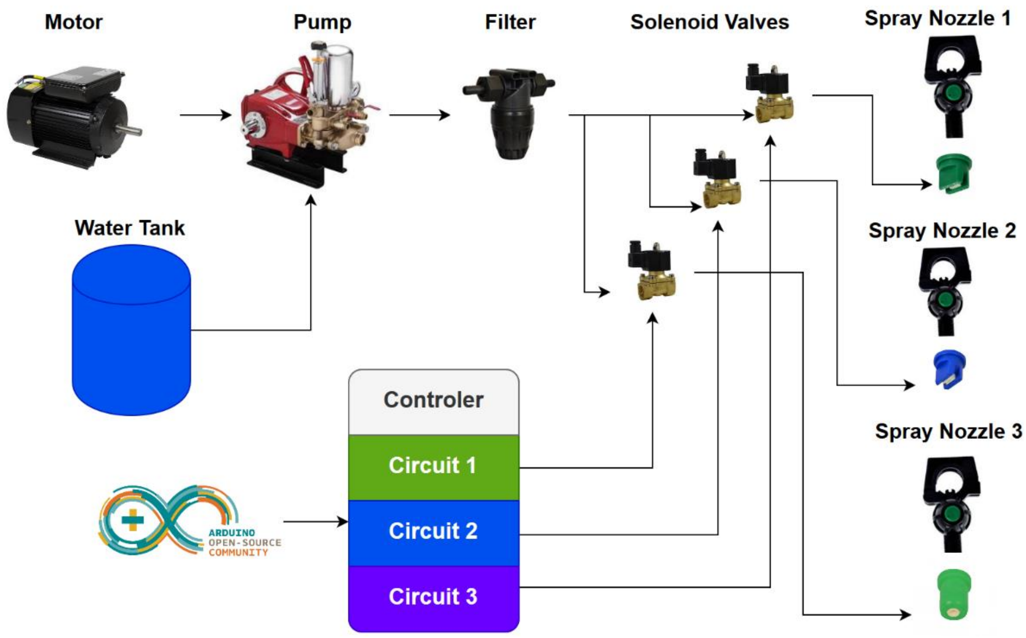
In view of this situation, the scientific community and the industry have been working to optimize agricultural spraying. Ultra-low volume (ULV) application is a promising technique in which quantities of less than 50 L ha^{-1} are applied (the conventional amount is 150–250 L ha^{-1}) (BAYER *et al*., 2011), thereby increasing the number of hectares covered per application. However, there are still questions regarding the quality of droplet size and distribution in ULV spraying. This study aimed to 1) to develop an automated boom sprayer prototype with three different nozzle sections for laboratory testing, 2) evaluate the accuracy of the pressure gauge and nozzle output, and 3) evaluate the parameters related to the application technology: volumetric median diameter, droplet density, droplet volume, and coverage (%) of the sprayer.

MATERIAL AND METHODS

Automated boom sprayer

We developed an automated section control prototype that allows the operator to change between three sections through command buttons without manually handling the nozzles. The Arduino microcontroller activates one of three circuits, each controlling a different section of the sprayer (Fig. 1). The prototype was assembled on a 2 × 0.90 × 0.90 m steel bench in the Laboratory of Precision Agriculture and Machinery (LAMAP) of the Western Paraná State University, Cascavel, Paraná, Brazil.

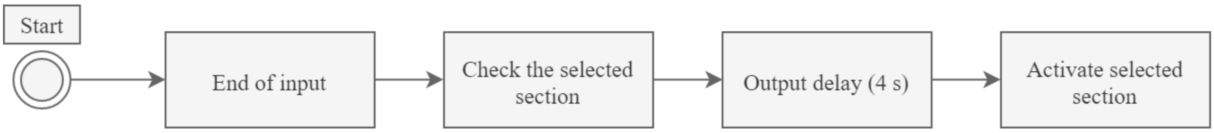
Figure 1. Flow chart of the automated boom sprayer prototype with an Arduino microcontroller.



Source: authors

The control panel consists of three command buttons and a 16 × 2 LCD display (16 columns × 2 rows), which provides information on the active section. Section activation is controlled by three 1/2-inch stainless steel solenoid valves containing a two-way servo control (diaphragm) that is normally closed, operating at 12 V, minimum pressure of 14.50 psi, and maximum pressure of 290.075 psi. A switched-mode power supply with an input of 127/220 V and an output of 12 V is connected to the valves. Solenoid valve control was programmed into the microcontroller using Arduino 1.6.1 software. The microcontroller provides an electric signal to activate the section chosen by the operator. A 4 s interval was included after each section selection to reduce the possibility of operator error (Fig. 2).

Figure 2. Flow chart of the circuits in the automated prototype.



Source: authors

Because most pesticides must be dissolved or suspended in water for application, the system was set up with a 200 L water tank. The circuit was pressurized using a piston pump coupled to a 2 HP, 3 phase, 4 pole motor operating at 220 V, 60 Hz, and 1800 rpm. The spray pump has a maximum flow rate of 18 L min^{-1} at 800 rpm and a maximum pressure of 580.151 psi.

The boom sprayer was assembled on a 2.45 m long, 0.23 m wide metal structure with three 2.65 m long sections, each containing 5 nozzles distant 0.50 m from each other. Nozzle spacing allowed a 60% spray overlap between adjacent nozzles.

Section booms were attached to a support with adjustable height (0.80–1.10 m). Sections were composed of five BD-015 (low-drift flat fan), AD-03 (anti-drift flat fan), or CV-IA-015 (air induction hollow cone) nozzles, which were supplied by Magnojet (Ibaiti, Paraná, Brazil). Nozzle specifications are shown in Table 1.

The flow rate of each nozzle was evaluated in the laboratory and compared with the values presented in the manufacturer's manual. All tests were carried out using a working pressure of 59.46 psi, as measured by a glycerin manometer. The tests were conducted from 2:00 p.m. to 6:00 p.m. on December 8, 2015, under a relative humidity of 86.20%, solar radiation of 498.49 W m^{-2}, precipitation of 0.0 mm, maximum temperature of 29.20 °C, and minimum temperature of 18.60 °C (SIMEPAR weather information system). According to the manufacturer, the flow rate at this working pressure is 700 mL min^{-1} for BD-015, 1,430 mL min^{-1} for AD-03 nozzle, and 700 mL min^{-1} for CV-IA-015. The flow rate was determined by gravimetric analysis. Nozzles were turned on for 60 s, and the liquid spray was collected in a 5 L container. The containers were weighed on a precision balance (± 0.002 kg). Ten repetitions were performed for each nozzle. Spray volume was calculated taking into account the density of water (1 kg L^{-1}).

Table 1. Technical characteristics of the spray nozzles used in the prototype.

Parameter	BD-015	AD-03	CV-IA-015
Pressure range (bar)	1–4.1	2–4.1	3.1–10.4
Recommended height (cm)	50–60	50–60	50–60
Recommended spacing (cm)	50	50	50
Manufacturer	Magnojet	Magnojet	Magnojet
Flow rate (L m^{-1})	0.36–0.70	1.00–1.43	0.62–1.10

Source: Manufacturer site, access link: http://www.magnojet.com.br

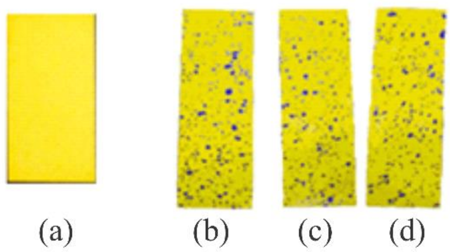
Droplet volume was assessed using 76 × 26 mm water-sensitive papers (Hypro®, Syngenta Crop Protection, Basel, Switzerland). Because the prototype is stationary, the water-sensitive papers were placed on top of a 1.10 × 0.10 m acrylic support on a remote-control mini-car (Fig. 3) moving at an average speed of 7 km h^{-1}. The spray coverage percentage was estimated by scanning the water-sensitive papers under a table scanner with 600 dpi resolution.

Images were processed using Gotas version 2.2 (EMBRAPA). This software was developed by the Brazilian Agricultural Research Corporation for analysis of pesticide deposition. Volumetric median diameter (VMD), droplet density, coverage percentage and droplet volume were determined. The relative span was calculated according to Eq. (1).

$$\text{Span} = \frac{D_{v90} - D_{v10}}{D_{v50}} \quad (1)$$

Where D_{v90} is the droplet diameter below which 90% of the particle diameters fall, D_{v50} is the volume median diameter (VMD), and D_{v10} is the droplet diameter below which 10% of the particle diameters fall.

Figure 3. Water-sensitive papers (a) after spraying with nozzles BD-015 (b), AD-03 (c), and CV-IA-015 (d).



Source: authors

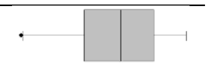
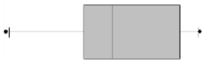
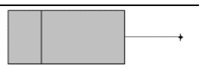
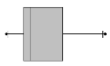
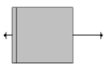
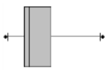
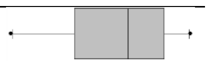
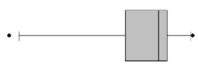
Statistical analysis

For analysis of data homogeneity and normality, we calculated the measures of central tendency (mean and median), dispersion (standard deviation, SD), coefficient of variation (CV), and distribution (skewness and kurtosis). CV was classified according to Pimentel and Garcia (2002) as low (homoscedasticity), for CV <10%; intermediate, for 10% < CV < 20%; high, for 20% < CV < 30%; and very high (heteroscedasticity), for CV >30%. Data analysis was performed using the R Core Team software (2021), and graphs were constructed using Statistica version 10 (StatSoft, Palo Alto, United States).

RESULTS AND DISCUSSION

The prototype showed good performance in tests simulating pesticide application. Table 2 presents the descriptive statistics for the flow rate of individual nozzles on the automated boom sprayer prototype. Most flow rate values were within the manufacturer's specifications, but AD-03 and CV-IA-015 had some results above the limit. The CV was less than 10% for all tests, indicating a balanced distribution of flow. The anti-drift flat fan nozzle AD-03 had a higher CV than other nozzle types.

Table 2. Flow rate (mL min^{-1}) delivered by individual nozzles on the automated boom sprayer prototype.

Nozzle number	Maximum	Minimum	Median	Mean	SD	CV	Boxplot
BD-015 (low-drift flat fan nozzle)							
1	738	640	699	696.2	31.70	4.55%	
2	755	670	704	706.3	27.95	3.96%	
3	725	640	722	706.6	27.90	3.95%	
4	730	667	702	704.6	20.98	2.98%	
5	780	660	737	726.5	36.07	4.96%	
AD-03 (anti-drift flat fan nozzle)							
1	1478	1190	1423	1386	111.77	8.06%	
2	1534	1290	1463	1450	69.33	4.78%	
3	1548	1240	1474	1438	94.84	6.59%	
4	1510	1296	1486	1443	82.73	5.73%	
5	1590	1180	1492	1450	119.01	8.20%	
CV-IA-015 (air induction hollow cone nozzle)							
1	706	660	690	702.3	10.57	1.50%	
2	738	675	706	707.6	18.13	2.56%	
3	746	696	705	709.4	16.12	2.27%	
4	750	625	727	710.3	8.76	1.23%	
5	782	616	754	713.5	6.24	0.88%	

CV, coefficient of variation; SD, standard deviation.

As can be seen from the control chart in Fig. 4, BD-015 produced flow rates within the maximum and minimum limits. Only 80% of the flow rates delivered by AD-03 were within the optimum range, with 18% below the minimum and 2% above the maximum (Fig. 5) CV-IA-015 had two points above the minimum limit (Fig. 6). The highest flow rates were obtained using the AD-03 section, which is in agreement with the results of Silva (2017), who observed that AD-03 produced larger drops and resulted in higher droplet deposition on the upper and lower leaves of bean plants than other nozzle types. In the current study, BD-015 delivered the lowest flow rate among the three nozzles. Bonadiman (2008) found that pesticide application using fine and medium nozzles (as defined by the manufacturer) was more efficient in controlling caterpillars in soybean than treatments using coarse nozzles. Note that the flow rate delivered by a nozzle varies with pressure; more specifically, the relationship between flow rate (in L min^{-1}) and pressure (in bar) is quadratic (MARONGONI, 2018). Therefore, to double the flow rate of a pesticide solution through the nozzle, it is necessary to quadruple the pressure. However, the higher the pressure, the greater the nozzle wear.

Figure 4. Control chart showing flow rates (mL min^{-1}) delivered by the BD-015 nozzle section of the automated boom sprayer prototype.

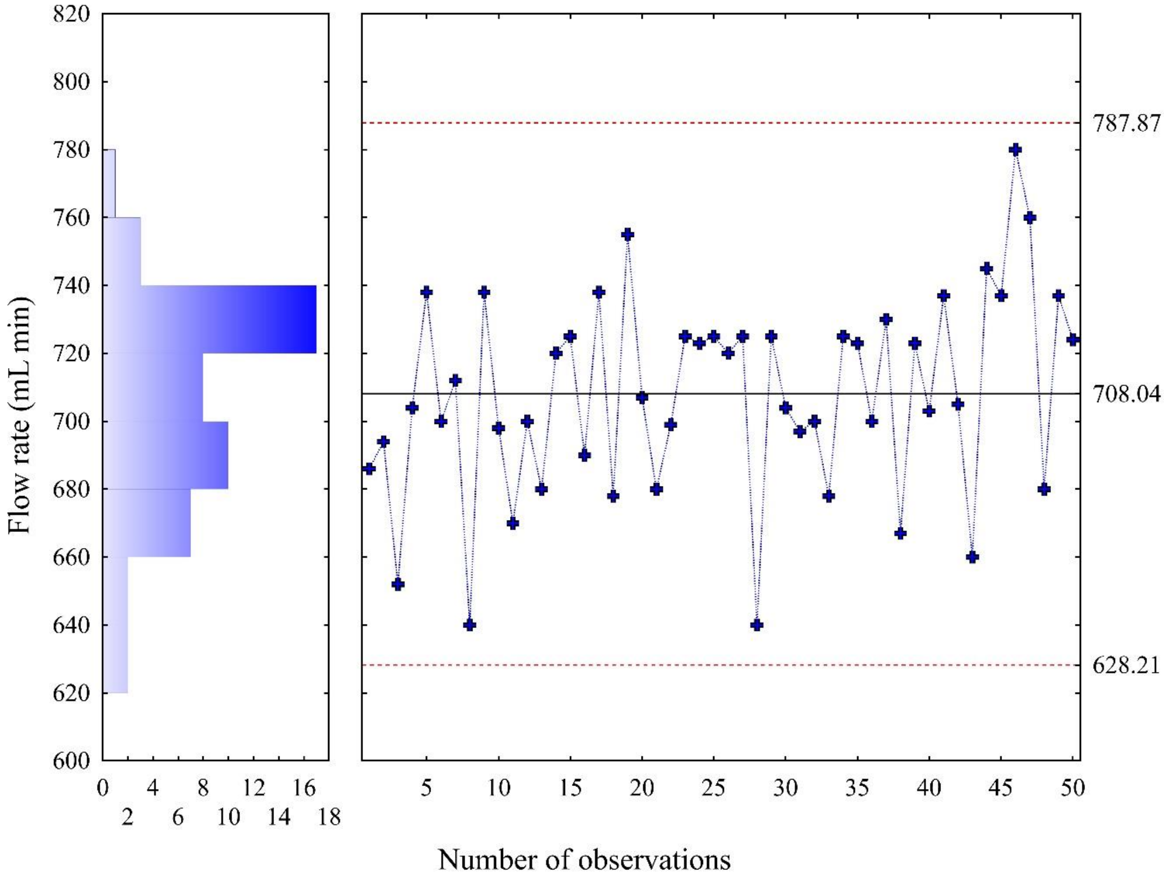
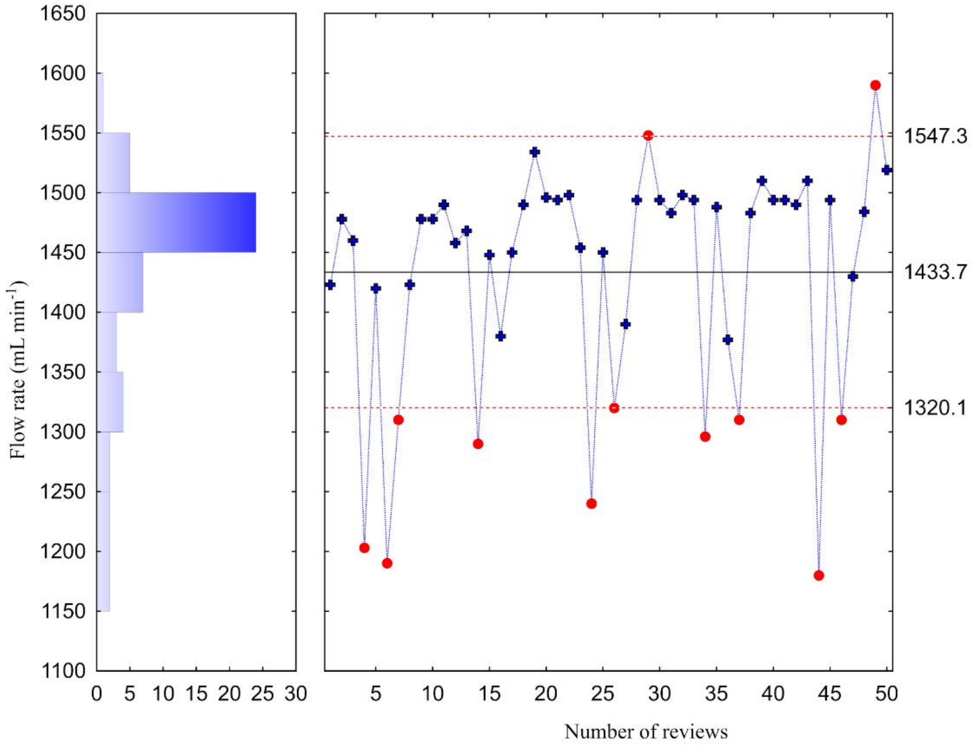
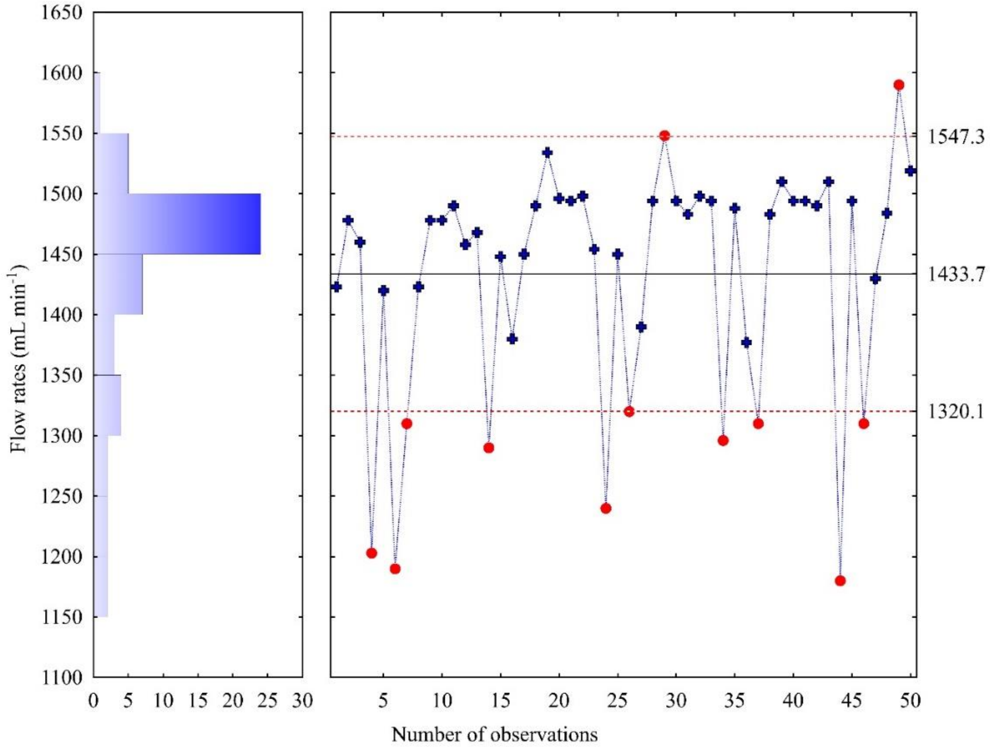


Figure 5. Control chart showing flow rates (mL min^{-1}) delivered by the AD-03 nozzle section of the automated boom sprayer prototype.



Source: authors**.**

Figure 6. Control chart showing flow rates (mL min^{-1}) delivered by the CV-IA-015 nozzle section of the automated boom sprayer prototype.



Source: authors.

Cunha, Teixeira and Vieira (2005) stated that results of pesticide spraying yields are variable and emphasized that the effectiveness of the application is determined by the amount of pesticide applied and the uniformity of spray distribution. For this reason, droplet size must be carefully considered when selecting spray nozzles for a particular application. However, most farmers do not attribute enough importance to this parameter, resulting in inefficient treatments and a high risk of pesticide drift (CHECHETTO *et al*., 2013).

The mean time required for nozzle change and stabilization was 3 s. The simplicity and speed of this procedure are a great advantage when the weather changes abruptly and a different type of nozzle needs to be used to reduce the risk of pesticide drift and off-target contamination. Santos *et al*. (2013), analyzing pesticide application in Sinop, Mato Grosso, Brazil, observed that the wind has a great influence on the process between 10 a.m. and 3 p.m., when the solar irradiation is high and wind gusts are more frequent. This observation reminds us that microclimatic and topoclimatic conditions should be taken into account in strategic planning, and should guide tactical decisions for optimal crop management. Such practices improve the resilience of agricultural systems in face of adverse weather conditions.

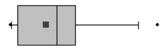
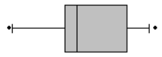
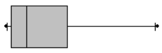
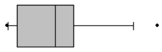
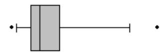
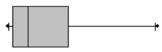
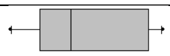
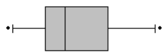
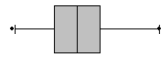
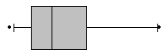
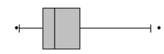
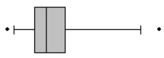
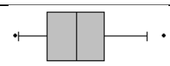
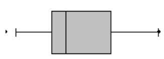
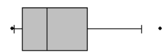
Exploratory analysis of droplet parameters revealed the versatility of the prototype. This characteristic increases the operator's control over spraying conditions, minimizes contact with chemicals, and improves the safety of the application. The prototype can be further enhanced to integrate a telemetry circuit for providing real-time meteorological information, a functionality not explored in this study. This technology can be adopted in the precision agriculture (PA) that has been advancing with new fronts, but it is still a challenge to connect a machine to a telemetry system (MOLIN, 2017) or sensors to the different types of data acquisition and transmission devices.

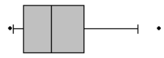
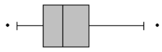
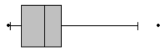
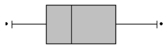
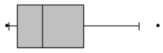
Droplet parameters (droplet number, diameter number, dispersion, droplet volume, droplet density, coverage, D_{v10}, VMD, D_{v90}, and span) of the nozzle sections were analyzed to better understand the application potential of the automated boom sprayer (Table 3). The CV-IA-015 section had a CV for droplet volume diameter of less than <34%. The AD-03 section showed the highest CV for droplet volume diameter. A uniform coverage of spray droplets necessitates a narrow volume distribution, or, in other words, a low CV of droplet parameters (VITÓRIA *et al*., 2014).

A mean VMD of less than 250 µm is associated with a higher risk of drift, especially of droplets smaller than 100 µm (CUNHA *et al*., 2004). All nozzles had a mean VMD above this limit. The AC-03 section produced droplets with a mean VMD of 546.24 µm because this nozzle type is coarser than the others.

AD-03 resulted in higher droplet density than CV-IA-015 and BD-015 (Table 3). This result indicates that AD-03 improved the interaction between the liquid and its target (water-sensitive paper), producing a greater number of drops per square centimeter (REPKE; TEIXEIRA, 2013). Span is a dimensionless variable expressing the spread of droplet size in the spray (MELLO, 2021). BD-015 had the lowest span, and AD-03 the highest (Table 3).

Table 3. Exploratory analysis of droplet parameters for the three nozzle sections of the automated boom sprayer prototype.

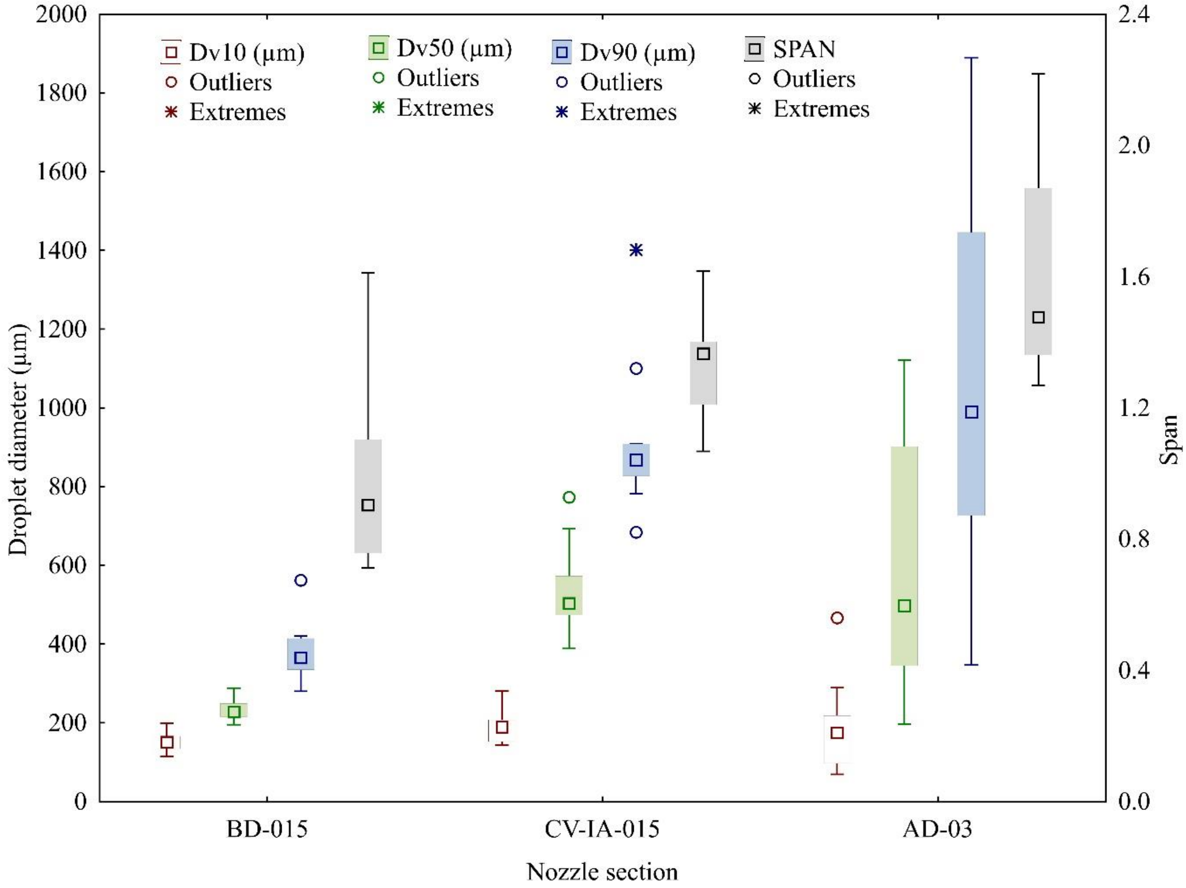
Parameter	Maximum	Minimum	Mean	Median	SD	CV	Boxplot
BD-015 (low-drift flat fan nozzle)							
Droplet number	6376.00	705.00	2468.92	2473.50	1636.05	66.27	
Diameter number	200.00	133.00	167.92	164.00	20.30	12.09	
Dispersion	2.68	0.71	1.25	0.97	0.69	54.84	
Density (droplets cm^{-2})	336.52	30.14	125.28	128.75	85.21	68.02	
Coverage (%)	7.83	2.63	5.49	6.07	1.92	34.92	
D_{v10} (µm)	199.42	93.88	147.04	150.76	29.15	19.83	
D_{v50} (µm)	505.57	163.41	251.64	227.95	87.25	34.67	
D_{v90} (µm)	1528.84	279.80	486.48	380.02	337.92	69.46	
Span	2.70	0.70	1.30	1.00	0.70	54.80	
CV-IA-015 (air induction hollow cone nozzle)							
Droplet number	3327.00	956.00	2130.58	1901.50	899.61	42.22	
Diameter number	215.00	110.00	155.42	149.00	31.62	20.35	
Dispersion	1.67	1.07	1.40	1.38	0.20	14.11	
Density (droplets cm^{-2})	158.48	41.88	98.79	94.59	42.74	43.27	
Coverage (%)	6.10	2.00	3.93	3.82	1.26	31.92	
D_{v10} (µm)	280.90	127.61	186.06	171.31	50.04	26.89	
D_{v50} (µm)	772.84	388.77	521.30	490.23	111.13	21.32	
D_{v90} (µm)	1401.26	684.12	909.88	867.45	185.20	20.35	
Span	1.67	1.07	1.40	1.38	0.20	14.10	
AD-03 (anti-drift flat fan nozzle)							
Droplet number	9852.00	1925.00	5169.42	5196.00	2200.40	42.57	
Diameter number	358.00	85.00	214.25	192.50	81.81	38.18	
Dispersion	2.95	1.27	1.77	1.66	0.50	27.97	

Density (droplets cm^{-2})	504.07	97.99	228.37	211.38	112.90	49.44	
Coverage (%)	20.48	1.12	8.99	8.24	5.03	55.99	
D_{v10} (µm)	466.68	69.06	180.81	165.02	109.01	60.29	
D_{v50} (µm)	1121.07	196.74	546.24	412.30	321.09	58.78	
D_{v90} (µm)	1889.73	346.53	1063.21	989.58	472.68	44.46	
Span	2.94	1.27	1.77	1.66	0.50	27.97	

D_{v10}, droplet diameter below which 10% of the particle diameters fall; D_{v50}, volume median diameter (VMD); D_{v90}, droplet diameter below which 90% of the particle diameters fall.

Droplet size can be determined either directly, in the air, or indirectly, by measuring the size of droplets on artificial targets. Indirect measurements simulate the impact of drops on natural targets and are important for evaluating spray drift and biological efficacy (MINGUELA; CUNHA, 2013). Droplet size was determined using water-sensitive paper. AD-03 produced the largest drops in comparison with the other nozzles. Rohde *et al*. (2021) observed that the spray deposition of AD and AD-IA nozzles were below the average for an effective pesticide application in the post-reproductive stage of maize. BD-015 showed lower droplet diameter values, that is, better deposition of spray droplets on the target. Cunha, Reis e Santos (2006) investigated the spray deposition of different nozzles and observed that a higher soybean canopy coverage was achieved when using fine nozzles. The authors observed that air induction nozzles result in low target coverage because of the large droplets, which cannot penetrate the plant canopy as efficiently as small droplets.

Figure 7. Boxplot of droplet parameters (D_{v10}, D_{v50}, D_{v90}, and span) for the three nozzle sections of the automated boom sprayer prototype.



Source: authors.

CONCLUSIONS

The developed prototype was effective and allowed a quick exchange of boom sections without affecting nozzle stability. In addition, it obliviates the need for direct contact between the operator and the nozzles, reducing the risk of contamination. The flow rate of nozzles at 59.46 psi was in accordance with the manufacturer's specifications, showing that the transition between boom sections was effectively carried out. The droplet parameters (VMD, droplet density, coverage percentage, and droplet volume) of each nozzle were within the ranges established by the manufacturer.

AUTHORSHIP CONTRIBUTION STATEMENT

ALVES, F.: Data acquisition, data analysis and interpretation, writing and reviewing the work. MAGGI, M.F.: research orientation and work review. MOREIRA, W.O.: data analysis and interpretation, work review. OLIVEIRA, D. D.: review of the work. BENEDUZZI, H.: Data interpretation, work review.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ACKNOWLEDGMENTS

The authors are grateful to the Universidade Estadual do Oeste do Paraná (UNIOESTE), the Instituto Federal do Paraná (IFPR), the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES, financing code 001) and the Fundação Parque Tecnológico Itaipu (FPTI), for the support received.

REFERENCES

BALSARI, P.; GIL, E.; MARUCCO, P.; ZANDE, J. C.; NUYTTENS, D.; HERBST, A.; GALLART, M. Field-crop-sprayer potential drift measured using test bench: Effects of boom height and nozzle type. **Biosystems engineering**, v. 154, p. 3-13, 2017. https://doi.org/10.1016/j.biosystemseng.2016.10.015.

BAIO, F. H. R.; ANTUNIASSI, U. R.; CASTILHO, B. R.; TEODORO, P. E.; SILVA, E. E. Factors affecting aerial spray drift in the Brazilian Cerrado. **Plos one**, v. 14, n. 2, p. e0212289, 2019. https://doi.org/10.1371/journal.pone.0212289.

BAYER, T.; COSTA, I. F. D.; LENZ, G.; ZEMOLIN, C.; MARQUES, L. N.; STEFANELO, M. S. Equipamentos de pulverização aérea e taxas de aplicação de fungicida na cultura do arroz irrigado. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 15, n. 2, p. 192-198, 2011. https://dx.doi.org/10.1590/S1415-43662011000200007

BONADIMAN, R. **Pontas de Pulverização e volumes de calda no controle de *Anticarsia gemmatalis* Hubner, 1818 e *Piezodorus guildinii* (Westwood, 1837) na cultura da soja *Glycine max***. 70f. Mestrado (Programa de Pós-graduação em Engenharia Agrícola, Área de concentração Mecanização Agrícola) – Universidade Federal de Santa Maria, Santa Maria, 2008. Disponível em: < https://repositorio.ufsm.br/bitstream/handle/1/7495/RAFAELBONADIMAN.pdf >. Acesso em:13 jun. 2019.

CHECHETTO, R. G.; ANTUNIASSI, U. R.; MOTA, A. A. B.; CARVALHO, F. K.; E SILVA, A. C. A.; VILELA, C. M. Influence of spray nozzles and adjuvants in drift reduction potential in wind tunnel. **Semina: Ciências Agrárias**, v. 34, n. 1, p. 37-46, 2013. http://dx.doi.org/10.5433/1679-0359.2013v34n1p37.

CUNHA, J. P. A. R.; REIS, E. F.; SANTOS, R. O. Controle químico da ferrugem asiática da soja em função de ponta de pulverização e de volume de calda**. Ciência Rural**, v. 36, n. 5, p. 1360-1366, 2006. http://dx.doi.org/10.1590/S0103-84782006000500003.

CUNHA, J. P. A. R.; TEIXEIRA, M. M.; VIEIRA, R. F. Avaliação de pontas de pulverização hidráulicas na aplicação de fungicida em feijoeiro. **Ciência Rural**, v. *35, n.* 5, p. 1069-1074, 2005. http://dx.doi.org/10.1590/S0103-84782005000500013.

CUNHA. J. A. R.; TEIXEIRA, M. M.; VIEIRA, R. F.; FERNANDES, H. C.; COURY, J. R. Espectro de gotas de bicos de pulverização hidráulicos de jato plano e de jato cônico vazio. **Pesquisa Agropecuária Brasileira**, Brasília, v. 39, n. 10, p. 977- 985, out. 2004. https://doi.org/10.1590/S0100-204X2004001000005.

JULIATTI, F. C.; NASCIMENTO C.; REZENDE, A. A. Avaliação de diferentes pontas e volumes de pulverização na aplicação de fungicida na cultura do milho. *Summa phytopathol, v.* 36, n. 3, p. 216-221, 2010. http://dx.doi.org/10.1590/S0100-54052010000300005.

GRAMMATIKIS, P. R.; SARIGIANNIDIS, P.; LAGKAS, T.; MOSCHOLIOS I. A compilation of UAV applications for precision agriculture. Computer Networks, v. 172, p. 107148, 2020. https://doi.org/10.1016/j.comnet.2020.107148.

KAUR, R.; MAVI, G. K.; RAGHAV, S.; KHAN, I. Pesticides classification and its impact on environment. Int. J. Curr. Microbiol. Appl. Sci, v. 8, n. 3, p. 1889-1897, 2019. https://doi.org/10.20546/ijcmas.2019.803.224.

MARONGONI, A. J. **Influência da pressão e da ponta de pulverização na distribuição de caldas em pulverizadores costais manuais**. 41f. Mestrado (Faculdade de Ciências Agrárias e Veterinárias) – Universidade Estadual Paulista, Jaboticabal, 2018. Disponível em: < https://repositorio.unesp.br/bitstream/handle/11449/153874/marangonijunior_a_me_jabo.pdf?sequence=3 >. Acesso em: 13 jun. 2019.

MELLO, C. E. L.; DO CARMO, E. L.; BRAZ, G. B. P.; SIMON, G. A.; DE SOUSA, J. V. A.; DOS REIS, A. C. P.; & DE ARAÚJO, G. E. S. The effects of rates, nozzle tips and electrostatics on the quality of sprayed applications on soybean crop. **Journal of Plant Protection Research**, v. 61, n. 4, 2021. https://doi.org/10.24425/jppr.2021.139239

MINGUELA, J. V.; CUNHA, J. P. Manual de Aplicação de Produtos Fitossanitários. 1. ed. Viçosa, 2013. 588 p.

MOHAMED, N.; TAHA, R.M.; RAZAK, U.N.A.A.; ELIAS, H. The Role of Plant Growth Regulators in the Development of in vitro Flowering, Histology and Ultrastructural Studies in Impatiens balsamina cv. Dwarf Bush. **Planta Daninha**, v. 36, e018165357, Epub March 29, 2018.https://dx.doi.org/10.1590/s0100-83582018360100013

MOLIN, J. P. Agricultura de precisão: **números do mercado brasileiro**. Agricultura de Precisão, Boletim Técnico, Ed. 03. p. 7. 2017. Disponível em:< http://www.agriculturadeprecisao.org.br/>: acessado em: 31 de maio de 2019.

PIMENTEL, G. F.; GARCIA, C. H. **Estatística aplicada a experimentos agronômicos e florestais**. Volume 11. Piracicaba: FEALQ, 309 p, 2002.

R CORE TEAM. R: **A language and environment for statistical computing**. R Foundation for Statistical Computing, Vienna, Austria, 2021. https://www.R-project.org/.

REPKE, D.; TEIXEIRA, D. A. **Avaliação da Densidade de Gotas Durante a Pulverização Sobre Diferentes Arranjos Espaciais na Cultura do Amendo**im. Centro Paula Souza, Pompeia, Governo de São Paulo, Junho, 2013. Disponível em: < http://happyslide.org/doc/578606/avalia%C3%A7%C3%A3o-da-densidade-de-gotasdurante-a-pulveriza%C3%A7%C3%A3o-sobre >. Acesso em: 08 jun. 2019.

ROHDE, E. H.; MENEGHEL, B. de C. P. Avaliação de diferentes pontas e volumes de pulverização na aplicação de fungicida no milho. **Revista Cultivando o Saber**, v. 14, p. 95-107, 2021.

SILVA, R. **Pulverização hidráulica de fungicida na produtividade do feijoeiro comum**. 17f. Trabalho de Conclusão de Curso – Universidade Federal de Uberlândia, Monte Carmelo, 2017. Disponível em: < https://repositorio.ufu.br/bitstream/123456789/19423/3/PulverizacaoHidraulicaFungicida.pdf >. Acesso em: 19 jun. 2019.

Statsoft, Inc. STATISTICA (data analysis software system), version 10, 2001.

VITÓRIA, E. L.; ROCHA, F. C. N.; CHAGAS, K.; TEIXEIRA, M. M.; QUIRINO, A. L. S.; SANTIAGO, H. Distribuição volumétrica e espectro de gotas de pontas de pulverização de jato cônico vazio DDC2 novas e usadas. **Revista Agro@ mbiente on-Line**, v. 8, n. 3, p. 368-376, 2014. ttp://dx.doi.org/10.18227/1982-8470ragro.v8i3.1831.